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Vehicular Impact Tests Of Precast Concrete Median Barriers With Corrugated Ends And Tensioned Cables

FINAL REPORT
JUNE 1978

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

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This study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

Two vehicular impact tests were conducted on a precast concrete median barrier (CMB) composed of 12.5 ft (3.81 m) segments with corrugated shear key ends. The barrier segments were connected by a continuous tensioned cable. Test parameters were as follows:

Precast Type 50V on expanded polystyrene pad	Test 331:	4680 lb vehicle/63 mph/25° (2120 kg vehicle/28 m/s/0.44 rad)
Precast Type 50V on grout bed	Test 332:	4600 lb vehicle/60 mph/25° (2090 kg vehicle/27 m/s/0.44 rad)

Both barriers were considered to be structurally inadequate due to excessive lateral barrier deflection, vehicle vaulting, and extensive concrete spalling. The expanded polystyrene pad and the cable did little to restrain barrier movement. The grout bed restraint was also ineffective; however, a better grout design and longer barrier segments might have improved the performance of the barrier somewhat.

Based on these test results, precast Type 50V CMB is not being recommended for use as a temporary or permanent barrier on California highways. Also, an existing permanent barrier installation similar in design to the barrier used in Test 332 will be replaced by a continuous concrete median barrier. The barrier was constructed prior to this research.

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DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

June 1978
FHWA No. D-4-150
TL No. 636882

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

VEHICULAR IMPACT TESTS
OF PRECAST CONCRETE MEDIAN BARRIERS
WITH CORRUGATED ENDS
AND TENSIONED CABLES

Study made by ....Structural Materials Branch

Under the Supervision of .... E. F. Nordlin, P. E.

Principal Investigator .... J. R. Stoker, P. E.

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and
D. M. Parks, P. E.

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

RLS/DMP:bjs
Attachment

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Jim Keesling	In charge of photo and electronic instrumentation data reduction, and preparation of the movie report.
Roy Steiner	Vehicle preparation.
Vince Martin Tom Ryan	Assistance with impact tests.
Robert Mortensen	Data and documentary photography.
Richard Johnson Delmar Gans William Ng.	Electronic instrumentation of test barriers, vehicles, and dummy.
Elmer Wigginton	Drafting of barrier plans, tables, and figures.
Larry Stevens	Reproduction of final report.

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Ed Tye Dick Smith	Office of Traffic Engineering
Ralph Bishop Philip Hale, Jr.	Office of Structures Design
John Evans	Value Engineering

The Utility Vault Company of Pleasanton, California, fabricated the test barrier segments and assembled the test barrier. Their careful workmanship and especially the cooperation of Jim Schack are appreciated.

INTRODUCTION

In the period 1971 through 1976 about 310 miles (499 km) of California Type 50 concrete median barrier (CMB) were built or under construction. Virtually none of this New Jersey safety-shaped barrier existed before that time in California. This CMB design has been built extensively in a short time span because of its good impact performance, its low construction and maintenance costs, and its pleasing appearance.

Many more miles of CMB are planned for construction in the next few years. With all this activity centered on CMB, several construction alternatives have been proposed in recent years, and a few have been subjected to vehicular impact tests (1, 2, 3, 4, 5)*.

Among the barriers tested by Caltrans were three precast CMB designs(4). Originally, precast CMB was used in California as a temporary barrier at construction sites for various purposes. However, in the above research study(4) on precast CMB it was desired to find a design that could be used both as a temporary and a permanent barrier. It was concluded that all three of the designs, which featured freestanding segments connected at each end with pins placed through embedded hooks, lacked the strength and stability of continuous cast-in-place or slipformed CMB. It was recommended that designs of this type only be used as temporary barriers where impact conditions were expected to be moderate such as impact speed/angles of 40 mph/20° (18 m/s/0.35 rad) to 60 mph/13° (27 m/s/0.23 rad). Precast CMB used as a permanent barrier would need anchorage to the ground and stronger joints.

Following the above study the Caltrans Headquarters Value Engineering Branch performed an analysis of precast CMB designs used by

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*Numbers in parentheses refer to a reference list at the end of this report.

other states including some which had been subjected to vehicular impact tests by other agencies(6, 7, 8, 9). They synthesized a new precast CMB design incorporating some of the best elements of other designs. It was hoped that this design, termed the Type 50V, would be satisfactory for both temporary and permanent use.

Short lengths of the CMB Type 50V were built as trial installations on three jobs. A description of one of those installations on Route 17 in District 04 is contained in the Appendix.

During the time that trial installations were being erected, plans were being made to conduct vehicular impact tests on the new design. Tests were planned on both temporary and permanent variations of the CMB Type 50V design.

The benefits anticipated from use of the CMB Type 50V design, assuming successful tests, were as follows:

- Equal or lower costs than the California standard Temporary Railing Type K when used on a volume basis, because of its reuse as a permanent barrier.

- Annual cost savings of $300,000 if 50,000 lineal feet (15 km) of CMB Type 50V annually were used as a temporary barrier and reused as a permanent barrier.

- Improved portability due to the suggested segment length of 12.5 ft (3.81 m) compared with a length of 20 ft (6.1 m) for Type K rail.

- Improved performance in redirection of impacting vehicles and better strength and stability to resist vehicle penetrations as compared with the Type K rail.

- Decreased time to full service of permanent CMB Type 50V on a grout pad since cast-in-place and slipformed CMB needs time to gain strength.

- Improved safety at some jobsites where the ease of installation of CMB Type 50V would minimize traffic delay and exposure of workers.

This report describes two vehicular impact tests on CMB Type 50V and evaluates the effectiveness of this new design.

Parameters for the tests were as follows:

Test No.	Base Support	Cable Tension (lbs)	Vehicle Wt.(lbs)	Impact Velocity (mph)	Impact Angle (degrees)
331	Expanded Polystyrene pads	17,640 & 14,780	4680	63	25
332	Grout pad	4,880	4600	60	25

Metric conversions: 1 lb force = 4.45 N;
1 lb mass = 0.454 kg;
1 mph = 0.447 m/s;
1 deg = 0.0175 rad

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions were based on the results of two vehicular impact tests conducted to determine the structural strength and stability of the Type 50V precast CMB design. The barriers were composed of nominally reinforced 12.5 ft (3.81 m) segments having corrugated shear key ends and strung on an unbonded tensioned cable running continuously through the lower portion of the barrier.

Test 331: 4680 lb vehicle/63 mph/25°
(2120 kg vehicle/28 m/s/0.44 rad)

This test barrier placed on a continuous expanded polystyrene pad representing a temporary barrier installation was judged to be structurally inadequate and unstable for the following reasons:

- A lateral barrier deflection of 27 inches (0.69 m) caused the test vehicle to become airborne and straddle the top of the barrier following initial impact.
- Extensive concrete spalling occurred at the corners of the barrier segments.
- The continuous expanded polystyrene pads used to provide base restraint did little to prevent barrier movement.
- Even though the tensioned cable absorbed an added average load of 9400 lbs (41.8 kN) during impact, it did not prevent barrier movement.

Test 332: 4600 lb vehicle/60 mph/25°
(2090 kg vehicle/27 m/s/0.44 rad)

This test barrier placed on a grout bed with the continuous cable anchorage "wrench" tight to simulate a recently installed experimental section of Type 50V was also judged to be structurally inadequate and unstable for the following reasons:

- Maximum lateral deflection of 28 1/2 inches (0.72 m) occurred during impact.

- The vehicle trajectory also probably would have been hazardous, similar to Test 331, if the test vehicle had not run over the cable guidance post prior to impact, causing the vehicle to roll toward the barrier.

- A flexural failure occurred in one of the barrier segments along with extensive concrete spalling at the corners of the barrier segments.

- There was poor bonding between the grout bed and the bottom of the test barrier. The grout bed as designed and built was ineffective in providing restraint for the barrier against lateral movement.

- The tensioned cable did not significantly help to restrain the barrier against lateral movement.

Recommendations

- Precast CMB designs, including the Type 50V, are not recommended for use in a permanent or interim installation where severe impact conditions - 4500 lb vehicle (2040 kg)/60 mph (27 m/s)/25° (0.44 rad) - are likely to occur unless totally restrained against lateral movement at the base.

- The minimum segment length for all types of precast CMB, including the Type 50V, used as a temporary barrier on construction and maintenance projects should be 20 feet (6.1 m) unless totally restrained at the base.

- Additional base restraint is needed on the existing Type 50V barrier on Route 17 in Santa Cruz County, 75 miles (121 km) south of San Francisco to prevent excessive lateral movements.

IMPLEMENTATION

Soon after the second test in this project it was recommended that additional lateral restraint be provided to the existing Type 50V CMB on Route 17 in Santa Cruz County. However, subsequently, additional impacts caused further movement and damage to the barrier. Therefore it was decided to replace the precast design with a continuous CMB, despite the higher cost of this alternative.

TECHNICAL DISCUSSION

Test Conditions

1. Test Facility

The two vehicle impact tests were conducted at the Caltrans Dynamic Test Facility in Bryte, California, on the western edge of Sacramento. The test area is flat and covered with asphaltic concrete pavement.

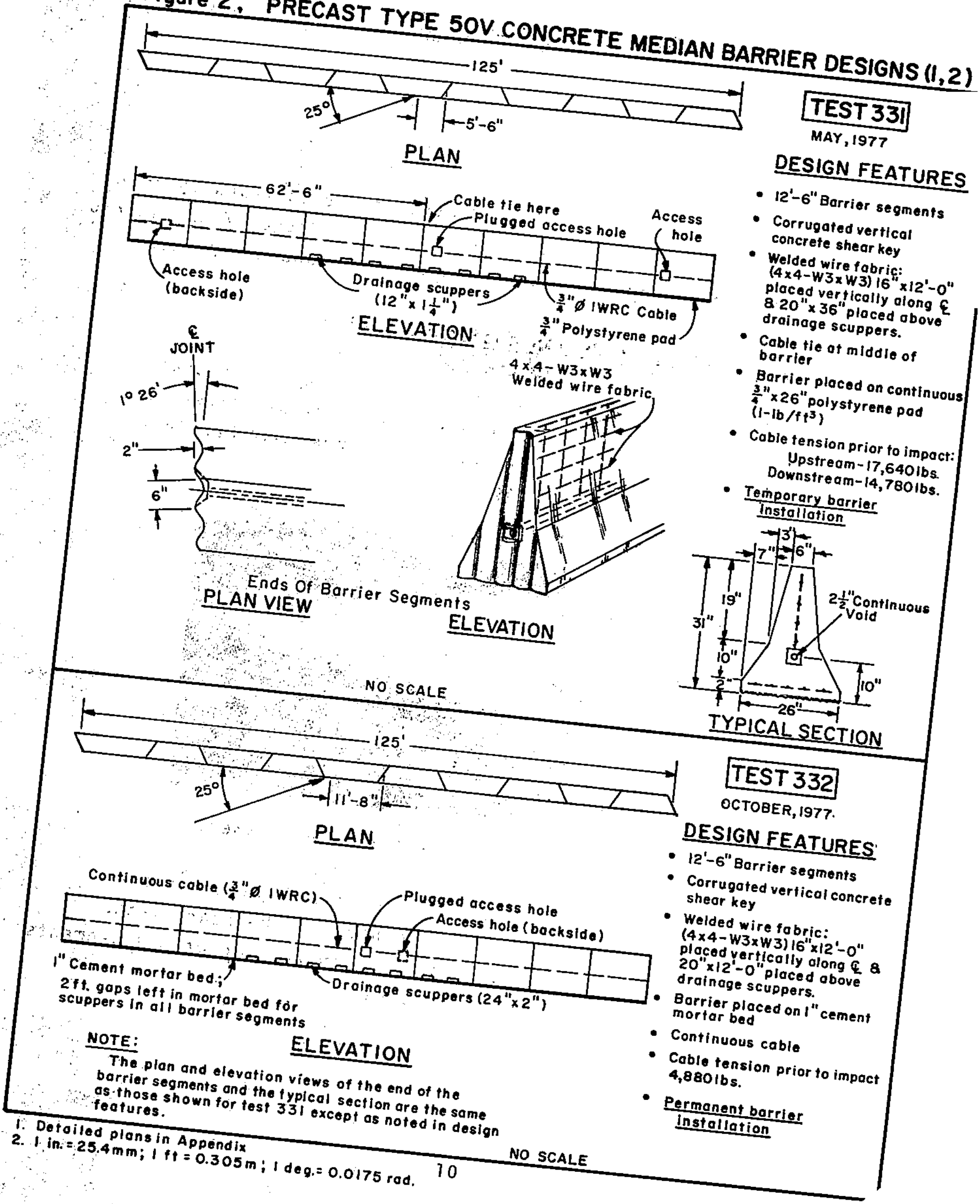
2. Test Barriers - Design and Construction

Figure 1 shows a typical test barrier segment. Key structural elements and design features for each test barrier are shown in Figure 2 for comparison. Complete details of the test barriers are contained in the Appendix, Figure 15A.

Figure 1, Typical Test Barrier Segment

Barrier segments were delivered to the test site by truck and placed in position by a small crane mounted on the rear of the delivery truck. Recessed lifting inserts in the top of the segments provided easy pickup points for the crane.

Figure 2, PRECAST TYPE 50V CONCRETE MEDIAN BARRIER DESIGNS (1,2)



1. Detailed plans in Appendix
2. 1 in.=25.4mm; 1 ft = 0.305m; 1 deg.= 0.0175 rad.

Expanded polystyrene pads used for Test 331 were laid on the swept pavement in position and the segments were set down lightly on top of them, Figure 3. The expanded polystyrene proved awkward to handle in the breeze and broke easily. Expanded polystyrene was used because another state had used short sections of it under the joints of precast CMB for temporary installations. The short sections of expanded polystyrene used by others compressed under the weight of the CMB segments and provided an improved interlock between the CMB and pavement surfaces.

Grout pads used for Test 332 were constructed in the same manner as those for the field installation described in the Appendix in an attempt to exactly simulate that barrier. The grout was mixed in a small mixer and placed in steel forms two or three barrier lengths ahead of the segments being placed, Figure 4. The AC pavement was swept but not wet down before placement of the grout. The grout was fairly stiff and as noted by post test observations did not slump enough to achieve active contact over the complete bottom area of all barrier segments. No leveling blocks were used to control segment height above ground.

As the segments were being placed, a cable was threaded through them, Figure 5. Swaged fittings with threaded stubs were attached to the cable ends, Figure 6. Two lengths of cable were used and spliced at mid-length as described in the Appendix in the section on electronic instrumentation. Steel bearing plates and nuts were used to tension the cables. The tightening was done with a large crescent wrench, Figure 5. For Test 331 a long steel pipe was used over the wrench to increase leverage. Considerable effort was required by two husky workers to reach the final cable tension. For Test 332 the cable was tensioned using the wrench without a pipe extension. It was tightened only to the point where extra effort was needed which simulated the tensioning method used for the field installation.

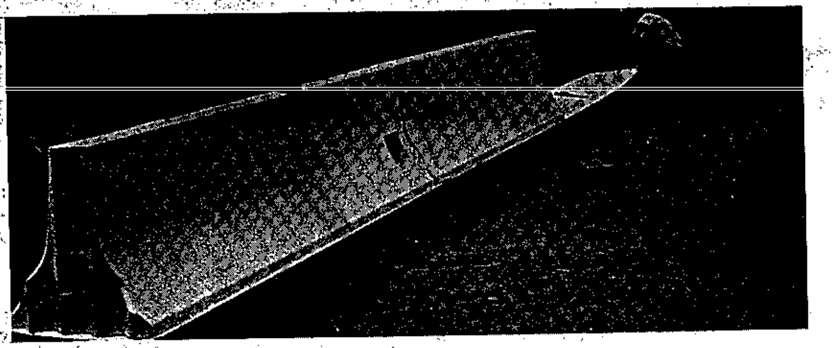


Figure 3. Laying Down Expanded Polystyrene Pad, Test 331.

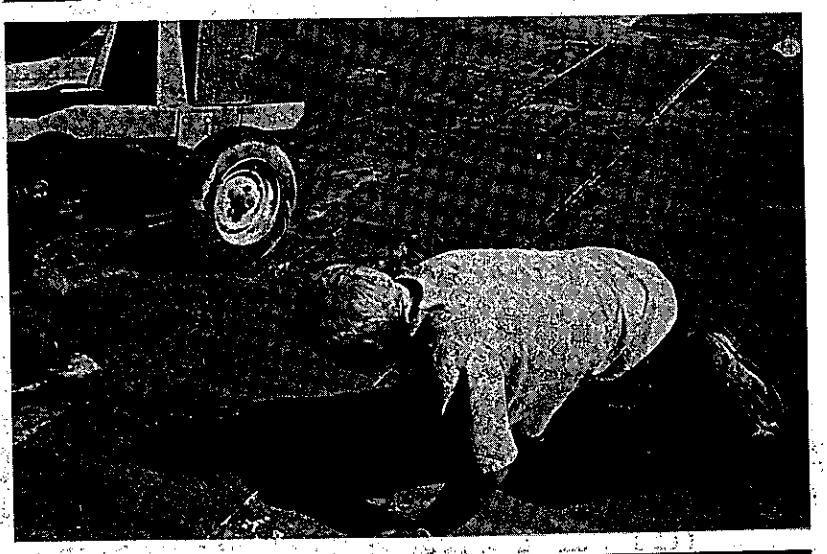


Figure 4. Grout Bed Construction, Test 332.

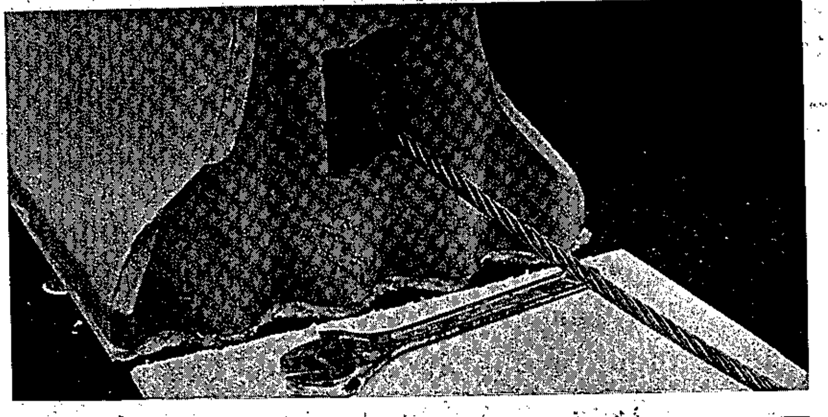


Figure 5. Cable Threaded Through Barrier Segment.

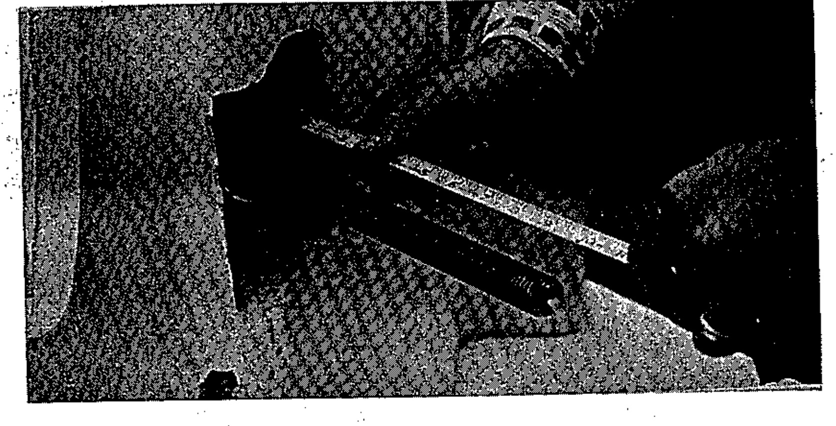


Figure 6. Threaded Stud, Nut, and Bearing Plate.

Segments with 1 ft (0.3 m) long scuppers and a handhole were placed near the point of impact to obtain the weakest barrier condition in Test 331. Segments with 2 ft (0.6 m) long scuppers were procured for Test 332. These were extra segments from the field installation which the precast fabricator had saved in his yard.

A summary of material sample tests of the strength of the barrier concrete, expanded polystyrene pads, grout, cables, and welded wire fabric is contained in the Appendix, Table 1A.

3. Test Vehicles

For Test 331 a 1973 Dodge Polara sedan weighing 4680 lbs (2120 kg) was used. For Test 332 a 1970 Ford Mercury Monterey sedan weighing 4600 lbs (2090 kg) was used. The vehicle weights included on-board instrumentation and one dummy. Both vehicles were in good condition, free of body damage and missing structural parts.

Both vehicles were self-propelled. Guidance was achieved with an anchored cable. No constraints were placed on the steering wheel. A short distance before the point of impact the vehicle ignition was turned off and the vehicle was released from the guidance cable. The vehicle brakes were applied remotely after the vehicle had impacted the barrier and established a post impact trajectory. Details about the vehicle equipment are contained in the Appendix.

4. Data Acquisition Systems

High speed and normal speed movie cameras and still cameras were used to record the impact events and the conditions of the vehicles and the barriers before and after impact.

An anthropomorphic dummy with accelerometers mounted in its head cavity was placed in the driver's seat to obtain motion and deceleration data. The dummy, Sierra Stan, Model P/N 292-850, manufactured by the Sierra Engineering Company, is a 50th percentile male weighing 165 lbs (75 kg). The dummy was restrained with a standard lap belt during the tests.

Accelerometers were also mounted on the floorboard of the test vehicles. Deceleration data were collected to judge impact severity and to evaluate vehicle occupant injury tolerances.

Houston Position Transducers were used to measure lateral movement and tilting of the first barrier segment impacted by the test vehicle. Load cells were placed at the end of the test barrier on the cable to measure the loads during tensioning and load increases during the vehicular impacts.

The Appendix contains a detailed description of: photographic equipment and data collection techniques; electronic instrumentation and data reduction methods; and instrumentation records.

Test Results

1. Test 331: 4680 lb vehicle/63 mph/25 degrees
   (2120 kg vehicle/28 m/s/0.44 rad)

A barrier deflection profile, test photos, and a summary of test data are contained in Figures 7 through 12.

a. Impact Description - Initial impact with the barrier occurred 5.5 ft (1.7 m) upstream of joint 5. The vehicle rode up the barrier face and became airborne. Primary barrier contact was 13.3 feet (4.06 m). As the vehicle ascended, it yawed clockwise and rolled away from the barrier to a maximum of 32° (0.56 rad). Due to the large barrier deflection, there was no "backslap" of the left rear fender of the vehicle with the barrier. Instead the left rear wheel of the vehicle climbed up segment 6 and rose above the barrier. The vehicle continued to yaw clockwise. While the vehicle yawed, it was traveling airborne over the top of the barrier and eventually three wheels were positioned beyond the backside of the barrier. Airborne distance was about 62 ft (19 m) and maximum rise was 6.2 feet (1.9 m). The vehicle lightly scraped the last few feet of the barrier and landed about 25 ft (7.6 m) beyond the downstream end of it at a yaw angle of about 60° (1.1 rad). Had the test barrier been longer, the vehicle could easily have toppled over it into the opposing traffic roadway. After landing, the vehicle straightened out slightly and slid/rolled to a stop 136 feet (42 m) beyond the end of the barrier, Figure 20.

b. Barrier Movement and Damage - Four barrier segments were displaced laterally during impact. Maximum deflection of 27 inches (0.69 m) occurred at joint 5, the first joint downstream from the point of impact, Figure 7. Analysis of the high speed film data revealed the barrier segments tilted back less than 6° (0.11 rad) during impact. The barrier deflection data in Figure 12A which are reliable for the initial portion of the impact confirm that there was minimal tilting.

Due to the large deflections and the tight fitting joints there was considerable spalling of the concrete at the corners of the segments, Figures 8 and 9. Figure 10 shows the damage and scuff marks on the barrier where primary vehicle contact occurred.

The upstream and downstream sections of cable which was spliced at mid-length had an increase in load of 10,000 lbs (44.5 kN) and 8,800 lbs (39.2 kN) respectively as they stretched into the deflected barrier profile. Load data is contained in Figure 14A in the Appendix. The reason for the load differences in the cable is contained in the Appendix under Electronic Instrumentation.

The barrier segments which moved laterally slid over the top of the expanded polystyrene pads, although some portions of the pads stayed under the barrier and slid across the pavement.

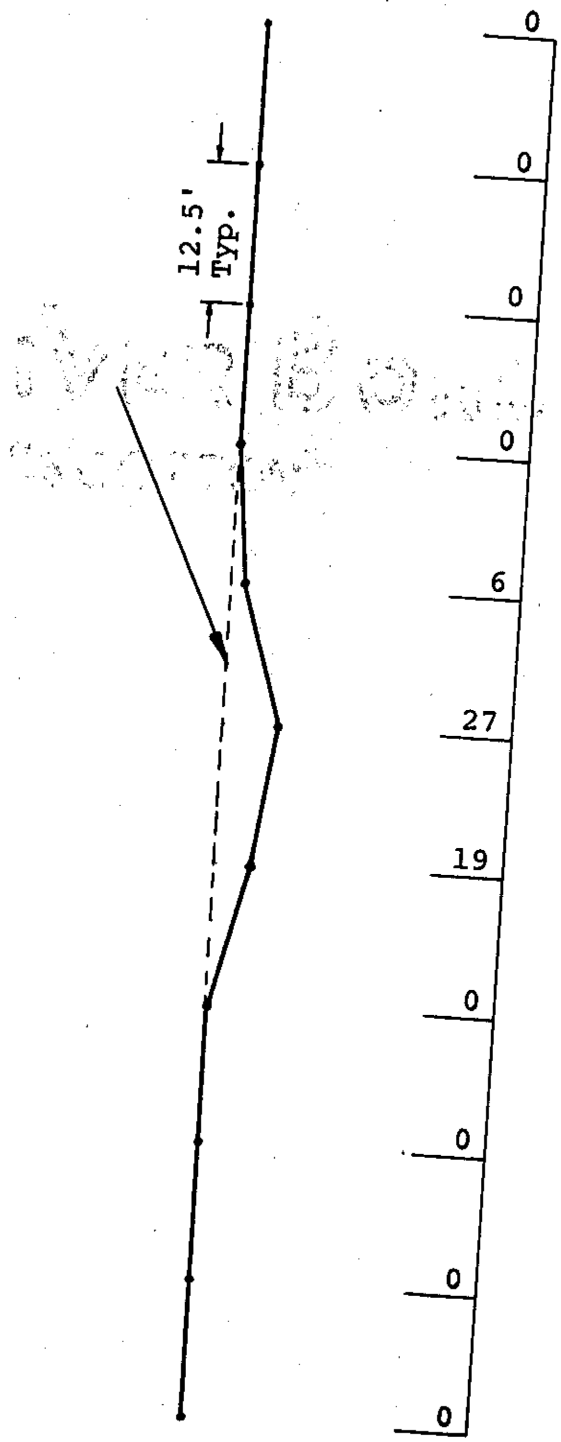
c. Vehicle Damage - Moderately severe crushing was sustained at the left front bumper and quarter panel and extended back to the left front door, Figure 11. There was virtually no other apparent damage around the remaining perimeter of the vehicle. No intrusion of vehicle or barrier parts into the passenger compartment occurred during the test. Damage measurement according to the Traffic Accident Scale (TAD)(9) was LFQ-5 and to the Vehicle Damage Index (VDI)(10) was 10LFEW3.

d. Dummy Behavior - A lap belt restraint was provided for the dummy. During impact the dummy slammed into the car door. Its head appeared to rap the door post sharply at that time and again when the car landed after being airborne. Apart from this vigorous bouncing, there did not appear to be any other damage to the dummy. Accelerometer and lap belt load data from the dummy are included in the Appendix, Figures 9A and 11A.

Figure 7. Permanent Lateral Displacement of Barrier Joints, inches

TEST 331

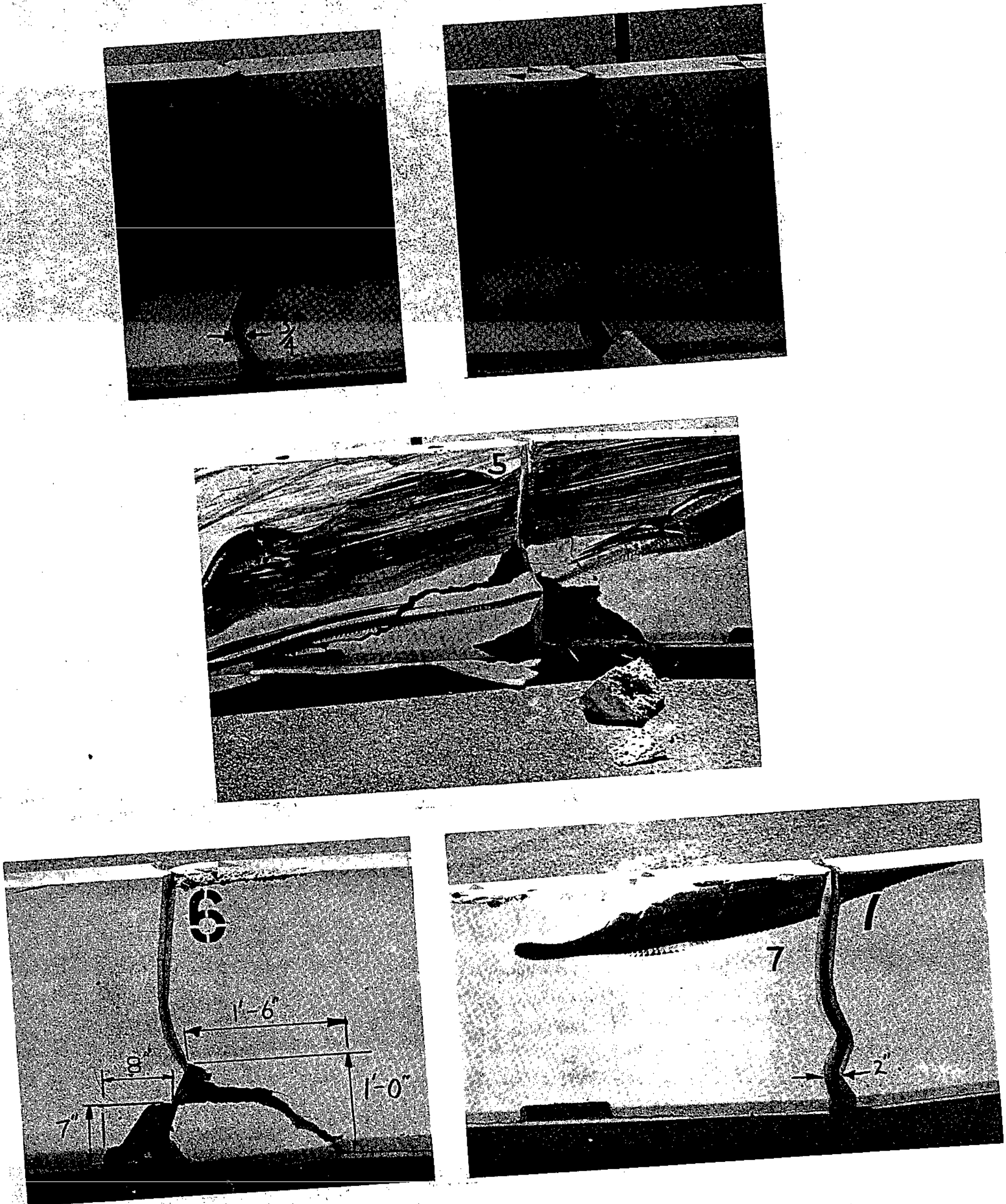
4680 lbs/63 mph/25°



No Scale

Metric Conversions

1 ft = 0.305 m
1 in = 25.4 mm
1 mph = 0.447 m/s
1 deg = 0.0175 rad
1 lb mass = 0.454 kg



<u>Figure 8</u>. Barrier Damage and Movement (impact side) at Joints 3, 4, 5, 6 and 7, Test 331.

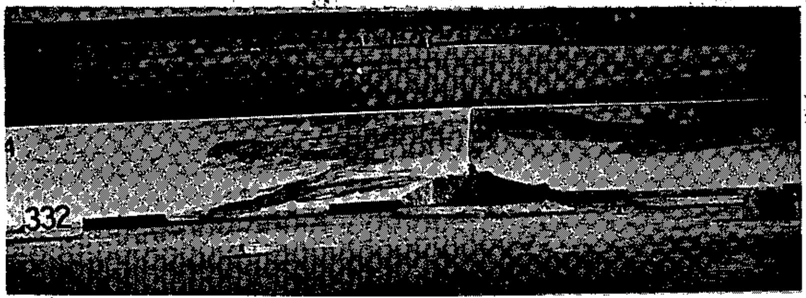


Figure 17. Primary Impact Area, Test 332.

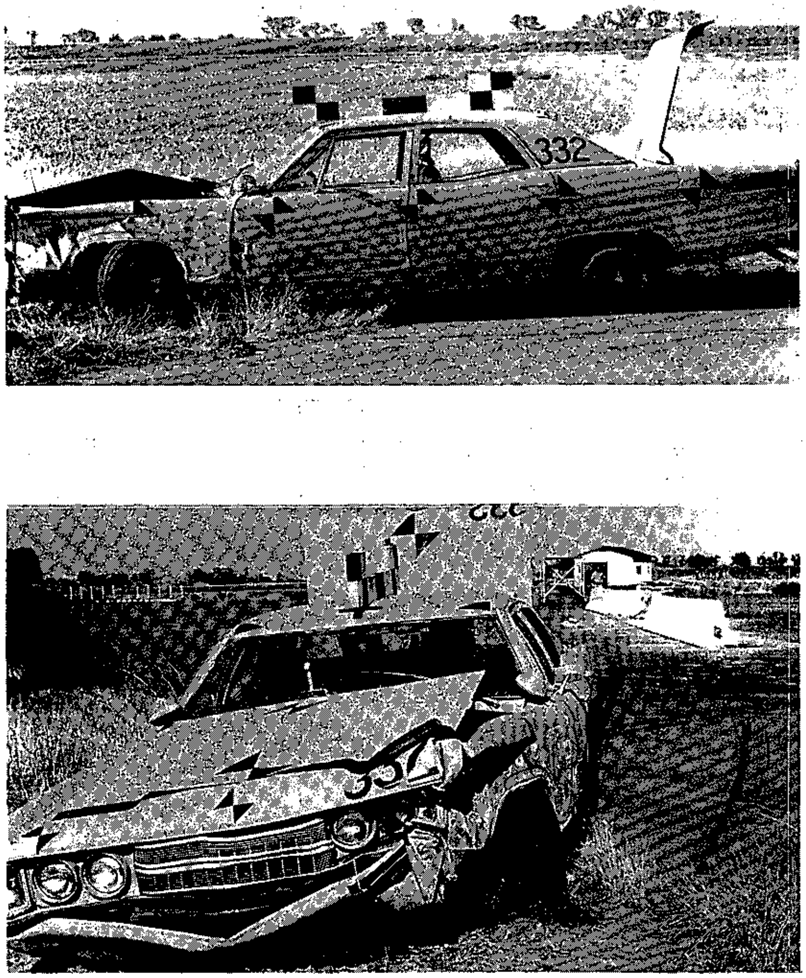
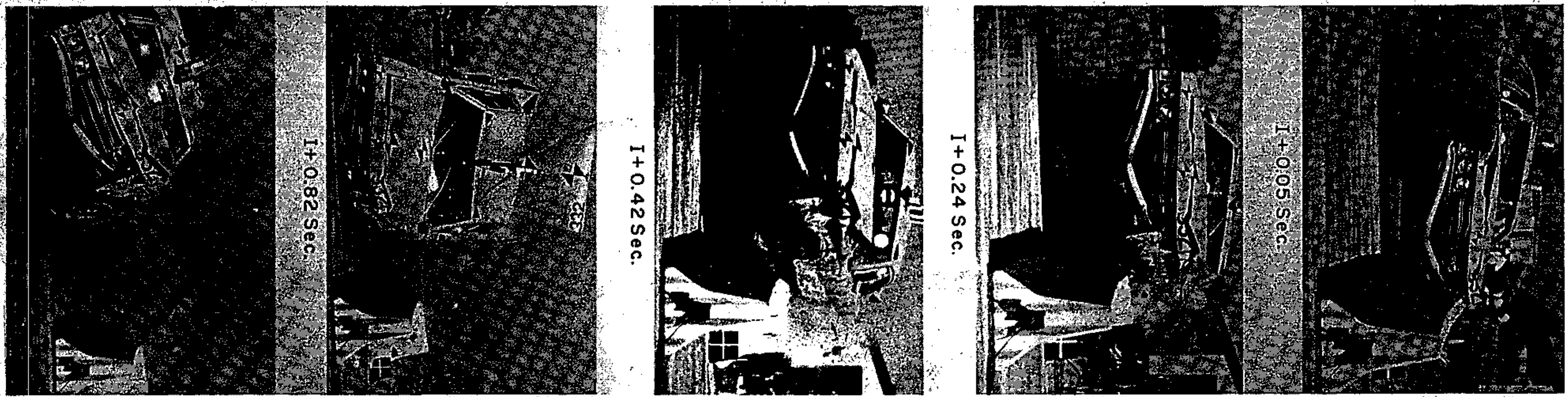


Figure 18. Vehicle Damage, Test 332.

DATA SUMMARY SHEET

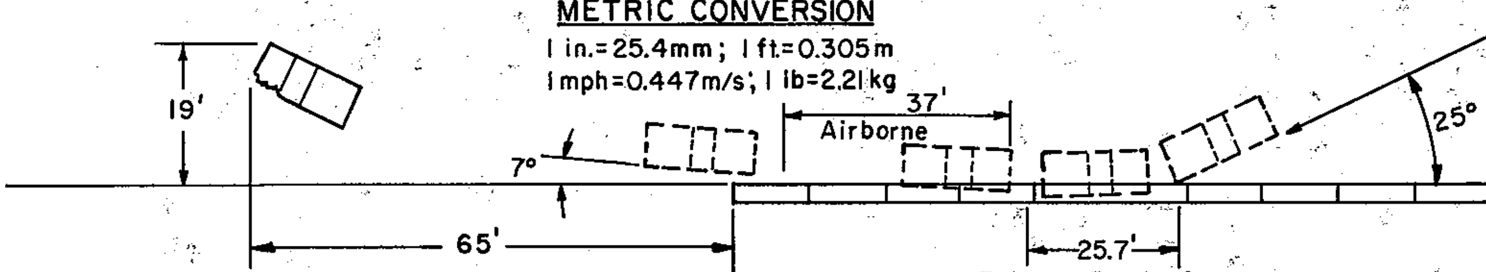
Figure 19,

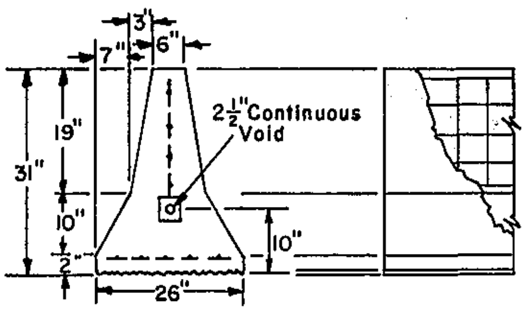


I+0.05 Sec. I+0.24 Sec. I+0.42 Sec. I+0.82 Sec. I+1.21 Sec.

METRIC CONVERSION

1 in.=25.4mm; 1 ft.=0.305m
1 mph=0.447m/s; 1 lb=2.21 kg





TYPICAL SECTION ELEVATION

NO SCALE

Barrier. . .Precast Type 50 V CMB on 1" Grout Pad with continuous 3/4" øIWRC Cable
Joint Connection. . . 2-in.deep corrugated vertical shear key with 6-in. pitch
Segment/barrier lengths, ft. 12.5/125
Cable Tension
  Load before impact, lbs. 4880
  Max. load increase during impact, lbs. 2720
Max. Perm.lateral joint displ. . . . . . .28.5 in
Vehicle Acceleration (max. 50m sec.avg.)
  Lateral . . . . 9.0g's
  Longitudinal. . . . . 4.9g's
Dummy Restraint . . . . Lap belt
Max. Vehicle Rise/Roll . . . . 5.3ft/-13°

Test No. 332
Date . . 10/4/77
Vehicle. . 1970 Ford Mercury Monterey
Vehicle wt..4600 lbs (w/dummy & Instrumen)
Impact speed . . . 60 mph
Impact angle. . .25°
Vehicle Damage:
TAD..LFQ-5
VDI..IOLFEW3

Discussion of Test Results

Safety performance of the precast CMB designs which were tested can be judged by comparison with three appraisal factors. These are defined in NCHRP Report 153, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances"(10). The factors are (1) structural adequacy, (2) impact severity, and (3) vehicle trajectory; they are discussed in the following three sections of the report.

Table 1 summarizes data from all the known vehicular impact tests by Caltrans and other agencies on precast CMB designs. This data can also be used on a relative basis for judging the safety performance of the CMB designs used in Tests 331 and 332.

1. Structural Adequacy

The CMB designs checked in Tests 331 and 332 met Part B of the NCHRP Report 153 criteria on structural adequacy:

> "B. The test article shall not pocket or snag the vehicle causing abrupt deceleration or spinout or shall not cause the vehicle to rollover. The vehicle shall remain upright during and after impact although moderate roll and pitching is acceptable. The integrity of passenger compartment must be maintained. There shall be no loose elements, fragments, or other debris that could penetrate the passenger compartment or present undue hazard to other traffic."

However, the CMB barrier segments did deflect excessively, or "pocket", in both tests to such an extent that they caused other serious problems. These problems relate to Part A of the NCHRP Report 153 criteria on structural adequacy which states:

TABLE I[14], DATA SUMMARY FOR PRECAST CMB CRASH TESTS

REF. NO	TEST NO.	TEST DATE	BARRIER: NAME	BARRIER: SEGMENT/ BARRIER LENGTHS	BARRIER: ANCHORAGE	BARRIER: CONNECTION BETWEEN SEGMENTS	VEHICLE TEST PARAMETERS: YEAR & MAKE	WEIGHT LBS.	IMPACT VELOCITY MPH.	IMPACT ANGLE	TOTAL KINETIC ENERGY ft. kips	LATERAL COMPONENT KINETIC ENERGY ft. kips	POINT OF IMPACT ft. (15)
CALIFORNIA	291	3/72	PRECAST NJ SHAPE	12.5/150	NONE	CLOSED PINNED JOINTS 7/8"ø STEEL ROD THROUGH OVERLAPPING #5 REBAR HOOKS CAST IN ENDS	1969 DODGE POLARA	4860	65	7	686	10	9
	292								68	23	752	115	11.5
	293	5/73		20/100		OPEN PINNED JOINT; 1"ø STL. ROD THROUGH OVERLAPPING 5/8"ø HOOKS			66	40	708	292	18.7
	294	11/74		20/120		CLOSED PINNED JOINT; STEEL ROD THROUGH OVERLAPPING 5/8"ø HOOKS	1968 DODGE POLARA	4700	39	25	239	43	9.2
	331	5/77	PRECAST NJ SHAPE W/6" TOP & 26" BASE	12.5/125	SEGMENTS SET ON CONTINUOUS 3/4" THICK STYROFOAM	CORRUGATED CONC. SHEAR KEY; CONTINUOUS STRESSED CABLE	1973 DODGE POLARA	4680	63	25	621	111	5.5
	332	10/77		12.5/125	1" GROUT BED, EXCEPT AT 2'-0 WIDE SCUPPERS		1970 MERCURY MONTEREY	4600	60	25	554	99	11.7
SWRI[1]	WCB-1	7/74	WELSBACH PRESTRESSED PRECAST NJ SHAPE	30/180	GROUT BED; 1"ø x 4' STL. DOWELS DRVN AT 1ST, 2ND 5TH & 6TH SEG	STL. ℄ MALE/FEMALE INTERLOCK	1963 MERCURY	4500	61.7	24	573	95	13.4
	WCB-1A	5/75					1968 PONTIAC	4500	62.7	24	592	98	13.2
	CMB-18	NA	PRECAST CONFIGURATION F SHAPE	20/100	SEGMENT ENDS SET ON 3/4" THICK STYROFOAM PADS	30"x3"x1 1/2" VERTICAL CONC. SHEAR KEY; 12"x3"x1/4" STEEL ℄ BOLTED AT BASE ON EACH SIDE OF JOINT.	NA	4500	62	25	578	103	5
	CMB-20				1" GROUT BED		1974 AMC AMBASSADOR		63	24.8	597	105	5.6
	CMB-24				SAME AS CMB-18		1974 AMC AMBASSADOR		56.4	24.1	478	80	4.7
TTI[2]	CMB-1	1975	PRECAST NJ SHAPE W/6" TOP & 27 1/2" BASE	30/90	1" A.C. BACK SIDE OF BARRIER	THREE #8x18" REBAR DOWELS CAST IN ONE SEGMENT & GROUTED TO NEXT SEGMENT	1966 PONTIAC	4500	60.5	23.5	550	88	7
	CMB-2			30/90	NONE	THREE #8x18" REBAR DOWELS SET IN FORMED GROOVES & GROUTED	1965 OLDS.	4540	59.8	24.2	543	91	7
FRANCE[3]	MI-SCB 01/253	8/72	PRECAST (FRENCH) NJ SHAPE W/20" BASE	20/200	CONC. FTG. 16"x20"x12" DEEP, 3.3FT FROM EACH SEGMT END CONNECTED TO SEGMENT W/1 DOWEL	LAPPED ENDS CONNECTED W/2-7/8"x6" HORIZ. PINS IN UPPER STEM OF CMB SECTIONS	404 PEUGEOT	2640	53	20	248	29	0
	MI-SCB 02-254	8/72					404 PEUGEOT	2660	59	10	310	9	~10
	MI-SCB 03/260	10/72					404 PEUGEOT	2420	50	26	202	39	~5

TEST NO.	VEHICLE BEHAVIOR & DAMAGE: VEHICLE DECELERATION G'S (10) LONG.	LAT.	EXIT ANGLE (16)	EXIT SPEED MPH(17)	MAX. RISE FT.(18)	MAX. ROLL ANGLE (19)	BARRIER CONTACT DISTANCE FT.	AIRBORNE DISTANCE FT.	MAX. REBOUND DISTANCE FT.(11)	TAD[12]	VDI[13]	BARRIER MOVEMENT: MAX. PERMANENT LATERAL DEFLECTION IN.	MAX. TILT ANGLE°	COMMENTARY
291	12	3.2[4]	ø	54	2.3	18	30.5	ø	26	LD-2	09LDSMI	6 1/4	0	VEHICLE REDIRECTED; MINOR CONCRETE SPALLING AT ONE JOINT.
292	6.8	11.8[4]	ø	55	7.0	61	18	56	12	LFQ-6 LBQ-3	10LFEW5 09LBEW2	22 1/4	16°	VEHICLE NOT REDIRECTED; VEHICLE LAUNCHED AIRBORNE LANDING NEARLY CROSSWISE TO ℄ OF BARRIER; SEGMENT FRACTURED AT IMPACT; MAJOR SPALLING AT THREE PINNED JOINTS; SEGMENTS LACKED SUFFICIENT REINFORCEMENT.
293	12.8[4]	6.5[4]	-10°	48	7.1	18	11	60	-26	FL-6 LBRT-5	11FYEW6 00TPGO4	11 1/8	SEGMENT TIPPED OVER	VEHICLE NOT REDIRECTED; VEHICLE LAUNCHED AIRBORNE BEHIND BARRIER & ROLLED OVER; BARRIER SEGMENT TIPPED OVER; CONNECTING HOOKS & RODS BENT.
294	2.7[4]	5.5[4]	4	30	2.7	33	36.5	16	70	LFQ-4	10LFEW3	5 1/2	9°	VEHICLE REDIRECTED (LOW IMPACT VELOCITY); MINOR CONCRETE SPALLING AT THREE PINNED JOINTS.
331	4.5[4]	5.0[4]	~0	53	6.2	32	13.3	62	36	LFQ-5	10LFEW3	27	6°	VEHICLE LAUNCHED ABOVE BARRIER & TRAVELED DIRECTLY OVER IT TO END OF BARRIER; VEHICLE YAWED CLOCKWISE & LANDED BEYOND END OF BARRIER; SEVERE CONCRETE SPALLING AT FIVE JOINTS; SEGMENTS NEAR IMPACT SLID OFF STYROFOAM PADS.
332	4.9[4]	9.0[4]	7	48	5.3	-13	25.7	37	19	LFQ-5	10LFEW3	28 1/2	0	VEHICLE REDIRECTED; SEVERE CONCRETE SPALLING AT FIVE JOINTS; CRACK ON BOTH SIDES OF IMPACTED SEGMENT THROUGH SCUPPER; SEGMENTS NEAR IMPACT SLID OFF GROUT PADS; SOME GROUT PADS LOST BOND WITH A.C. PAVEMENT.
WCB-1	9.9[5]	13.5[5]	NA				17.8	NA				0	NA	VEHICLE REDIRECTED; BARRIER SEPARATED FROM GROUT BED IN THE IMPACT AREA; NO OTHER BARRIER DAMAGE.
WCB-1A	9.4[5]	9.9[5]					17.6					2 1/2	NA	VEHICLE REDIRECTED; BARRIER SEPARATED FROM GROUT BED IN THE IMPACT AREA; CONCRETE CRACKING BACK SIDE OF FIRST SEGMENT DOWNSTREAM OF IMPACT.
CMB-18	NA													VEHICLE REDIRECTED; SEGMENT FRACTURED AT IMPACT AND 5.5 FT. PAST 1ST. JOINT DOWNSTREAM FROM IMPACT; MINIMAL SEGMENT REINFORCEMENT. 11 FT. SEGMENT DISLODGED FROM REST OF BARRIER AND TIPPED OVER.
CMB-20	6.1[5]	9.8[5]	NA	NA	NA	56	14.7	NA	NA	NA		0	NA	VEHICLE REDIRECTED; TENSION CRACKS AT LIFTING VOIDS LOCATED APPROX. 5 FT. BOTH SIDES OF JOINT 2. (1ST. JOINT DOWNSTREAM FROM IMPACT).
CMB-24	3.5[5]	4.9[5]	NA	NA	NA	26	44.5	NA	NA			41	NA	VEHICLE REDIRECT; SEGMENTS REMAINED ATTACHED; CONC. FAILURES AT JOINTS 1, 2 & 3; DIAGONAL CRACKING OF FEMALE JOINT.
CMB-1	1.6[6]	7.5[6]	7	48.0[9]	NA	18	NA	NA	NA	LFQ-6	10LFEW5	0	NA	VEHICLE REDIRECTED; NO BARRIER DAMAGE.
CMB-2	1.1[7]	6.3[7]	3	49.3[9]	NA	18	NA	NA	NA	LFQ-5	10LFEW3	13 1/2	NA	VEHICLE REDIRECTED; SEVERE CRACKING AT BOTH JOINTS.
MI-SCB 01/253	IMPACTOGRAPH USED		7	NO DATA			9	NO DATA		NA		0	NO DATA	VEHICLE REDIRECTED; VERTICAL CRACK IN ONE SEGMENT; THE ENDS OF THREE SEGMENTS DAMAGED.
MI-SCB 02-254			SMALL				15					0		VEHICLE REDIRECTED
MI-SCB 03/260	14/10[8]	12/7[8]	14				9					1		VEHICLE REDIRECTED; TWO SEGMENT ENDS DAMAGED; THREE FOOTINGS TILTED IN SOIL

(1) Southwest Research Institute, references 6, 7, & 8, in report

(2) Texas Transportation Institute, reference 9 in report

(3) Organisme National De Securite Routiere, Laboratoire des Chocs, reference 11 in report.

(4) Avg. of two max. 50 msec averages.

(5) Reduced from high speed film.

(6) Avg. for 206 msec. interval

(7) Avg. for 223 msec. interval.

(8) Peak/mean

(9) Velocity parallel to barrier

(10) Highest 50 msec. averages from accelerometer data unless noted.

(11) Max. distance (incl. width of vehicle) from face of barrier

(12) Vehicle Damage Scale (National Safety Council)

(13) Collision Deformation Classification (SAE J224a)

(14) 1 in=25.4mm; 1 ft.=0.305m; 1mph=0.447m/sec; 1 ft-k=1.36kJ

(15) Distance to nearest downstream joint

(16) Direction of travel of vehicle c.g. immediately following final contact with barrier.

(17) Speed of vehicle c.g. immediately following final contact with barrier.

(18) Max. trajectory height of either left front or left rear wheel of vehicle above ground.

(19) Max. rotation of vehicle about the longitudinal axis of vehicle away from face of barrier.

(20) ~=approx.

"A. The test article shall redirect the vehicle; hence, the vehicle shall not penetrate or vault over the installation."

In Test 331 the large barrier deflection caused the vehicle to become airborne on a hazardous trajectory over the top of the barrier. If the barrier had been longer, the vehicle easily might have toppled over the backside of the barrier or rolled over. In Reference 4 more weight was given to tilting of the barrier segments than to lateral deflection as the cause of vehicle vaulting. Due to the low tilt angle of under 6° (0.11 rad) in Test 331 and a lateral deflection more than that in a similar previous Caltrans test, Test 292(4), it now appears that large lateral deflection alone can be a primary cause of vehicle vaulting in severe impact tests. This negates any possible benefits claimed in the form of reduced vehicle decelerations caused by barrier deflection for this type of barrier. It should be noted that differences in vehicle suspensions and crushability also may affect vehicle vaulting tendencies during CMB impacts.

Large barrier deflections are also frequently undesirable where precast CMB is used close to new bridge falsework, the edge of a bridge deck, or in a narrow median.

In Test 332 the maximum barrier deflection was an inch more than in Test 331 but the vehicle was redirected in a less hazardous manner than in Test 331. Had the test vehicle not gone over the cable guidance post in Test 332, causing it to roll toward the barrier, it is speculated that the vehicle trajectory might have been similar to that in Test 331.

It had been hoped that the stressed cable and corrugated end shear keys featured in the barriers for Tests 331 and 332 would help minimize barrier movement. Comparison of Tests 331 and 332 with the other tests in Table 1 shows that other designs have been more effective. No freestanding designs or barriers set on expanded polystyrene pads (temporary barrier designs) have approached the performance of continuous CMB which typically is undamaged and unmoved after "strength test" impacts.

The only precast CMB designs which had no lateral movement when impacted were those used for Tests WCB-1, CMB-20 (SwRI) and CMB-1 (TTI), Table 1, as "permanent" CMB designs. These designs included barrier segment lengths of 20 or 30 feet (6.1 or 9.2 m), and a positive CMB base restraint consisting of a grout bed underneath the barrier or an asphalt concrete overlay against the back side of the barrier.

The helpfulness of a good base restraint in precast CMB design was recognized in reference 4 which describes the initial Caltrans tests on precast CMB. It was thought that the CMB Type 50V design with the corrugated shear key and cable tie plus an expanded polystyrene base or grout pad would be sufficient. These combined features proved inadequate.

In Test 331 a continuous expanded polystyrene pad was used to provide continuous base restraint. This was intended to reduce the influence of bending in the horizontal plane had the barrier segments been placed on short expanded polystyrene pads at the joints only, and thus, "simply supported". Unfortunately the expanded polystyrene was dense enough that, when used continuously, it compressed a very small amount. This prevented any kind of effective interlock between the expanded polystyrene surfaces, and the pavement and barrier surfaces. Had the expanded polystyrene been less dense and compressed more, it is still doubtful that this would have prevented barrier movement, although it might have been reduced somewhat.

Due to the large deflections of the barrier in Test 331, concern arose about the permanent installation of CMB Type 50V described in the Appendix. That barrier was set on a grout bed. Therefore, it was decided that the permanent design scheduled for examination in Test 332 be an exact replica of the field installation. Again it was hoped that the combined features of joint design and base restraint would minimize barrier movement.

The deflection in Test 332 was almost identical to that in Test 331; therefore, even the grout bed provided insufficient base restraint. Unfortunately, the grout bed design used for the field installation, and hence, for the test barrier, was not optimal. The pavement was not wet down prior to placement of the grout bed, the grout was quite stiff and prevented complete grout bed to barrier surface contact, and there were no designed keyways, other than serrations on the bottoms of the segments, in the barrier segments or pavement. It was acknowledged that a keyed grout bed design with tighter construction controls and longer barrier segments might have been more successful.

About the time Test 332 was conducted, it was learned that the permanent field installation had been hit several times and moved a few inches off its grout bed. As a result of this and Test 332, the field installation will be replaced with a continuous CMB.

The 3/4 inch (19 mm) diameter tensioned cables for Tests 331 and 332 had little effect on restraining lateral barrier movement. Both barriers deflected nearly the same amounts even though their bases were restrained differently and the loads in their cables were not the same. Since the cable, unlike a reinforcing bar, is not a composite part of the barrier, it does not resist any load until it binds against the wall of its void in the barrier and even this effect would be small. Such binding does not occur until after the barrier has initially deflected. The small prestressing force induced into the concrete of the test barriers, 40 psi (276 kPa) for Test 331 and 12 psi (83 kPa) for Test 332, was not large enough to resist lateral barrier movement. It is doubtful that any additional prestress of the one cable would have had a significant effect on the performance of the barrier.

A prestressing force larger than about 50 psi (345 kPa) would require special prestressing equipment which would increase installation costs. Other potential problems associated with the cable include the difficulty of removing damaged barrier segments, specifying correct cable lengths for each job, excessive cable stretch between cable ties, and determining the amount of tension in each cable for each field installation. These drawbacks became more apparent as the project progressed. Overall the unbonded tensioned cables do not seem to be useful structural elements for precast CMB.

It should be noted that in both Tests 331 and 332 there was extensive spalling of the corners of the barrier segments which deflected. Also, a flexural failure occurred near the middle of the first barrier segment hit during Test 332. These segments would all need to be replaced. This represents less than desirable structural adequacy when compared with the performance of continuous CMB which is typically undamaged in severe impact tests.

In comparing all the tests described in Table 1 it was concluded that resistance to the movement of precast CMB could best be provided with a good base restraint. Barrier segments as long and heavy as possible would enhance this resistance. Without these two factors, none of the joint designs tested to date are effective in resisting movement. It appears at this time that any joint design which provides adequate moment resistance to prevent barrier movement and localized spalling failures would be too expensive. However, low cost positive joint connections still seem desirable to limit barrier deflection, to prevent vehicle penetration, and to add to the overall strength of the barrier.

Due to the various deficiencies in the CMB Type 50V design described above, it was concluded that the design was structurally inadequate when judged by the standards of NCHRP Report 153. Furthermore, there are other tested precast CMB designs or variations of those designs which would perform better than the CMB Type 50V.

It is possible, however, that the CMB Type 50V design like some other precast CMB designs may perform fairly well when subjected to the more prevalent moderate severity impacts expected along highways.

2. Impact Severity

In NCHRP Report 153A, the impact severity criteria for longitudinal barriers apply only to vehicle impact angles of 15° (0.26 rad) or less. The criteria refer to vehicular deceleration values as a measure of the probable severity of passenger injuries. The recommended deceleration limits are as follows:

"A. Where test article functions by redirecting vehicle, maximum vehicle acceleration (50 ms avg) measured near the center of mass should be less than the following values:

Maximum Vehicle Accelerations (g's)*

Lateral	Longitudinal	Total	Remarks
3	5	6	Preferred
5	10	12	Acceptable"

*1 G = 9.82 m/s^2

These limits represent a threshold beyond which disabling injury or fatality may be expected. The "preferred" levels assume no seat belt restraints and the "acceptable" levels assume lap belt restraints but no shoulder belt restraints.

As a point of interest, the deceleration levels for the 25° (.44 rad) angle impacts in Tests 331 and 332 can be compared with the above table. The lateral decelerations were 5.0 and 9.0 G's (49 and 88 m/s^2) respectively and the longitudinal decelerations were 4.5 and 4.9 G's (44 and 48 m/s^2) respectively. The longitudinal readings were in the "preferred" range, but the lateral readings were at or over the upper limit of the "acceptable" range. These deceleration values would not be considered unusual for severe impacts with precast CMB, with reference to Table 1. The vehicle deceleration versus time traces for Tests 331 and 332 are contained in the Appendix as Figures 7A and 8A. These charts show that the deceleration pulses resulting from a secondary impact of the rear of the vehicles with the barrier are similar in intensity to the initial pulses.

Use of a dummy is considered optional in NCHRP Report 153. An anthropomorphic dummy was used in both tests, and the electronic data from them is included as a further indication of impact severity. Deceleration versus time traces for accelerometers mounted in the head cavity of the dummy are included in the Appendix as Figures 9A and 10A. Lap belt load versus time traces are also contained in the Appendix as Figure 11A. None of the lap belt loads exceeded the 5,000 lb (22.3 kN) limit specified by Federal Motor Vehicle Safety Standard 208 which is a guideline cited in NCHRP Report 153. It is unclear why the maximum lap belt load in Test 332 was so much higher than that for Test 331. This may be due simply to the peculiarities of the vehicle trajectories.

3. Vehicle Trajectory

NCHRP Report 153 states:

> "A. After impact, the vehicle trajectory and final stopping position shall intrude a minimum distance into adjacent traffic lanes."

The text adds, "A subjective appraisal shall be made by the test engineer as to the trajectory hazard, based on vehicle exit speed and angle, maximum intrusion into a traffic lane or lanes during trajectory, and post crash controllability."

This appraisal factor was covered in the section on Structural Adequacy. In summary, the vehicle trajectory for Test 331 was judged unacceptable. That for Test 332 was relatively good; however, it might have been similar to the one in Test 331 had the vehicle not run over a vehicle guidance system knockoff post. Table 1 and Figures 12 and 19 provide data on the vehicle trajectory. Figures 20 and 21 show the post test trajectories for the two vehicles.

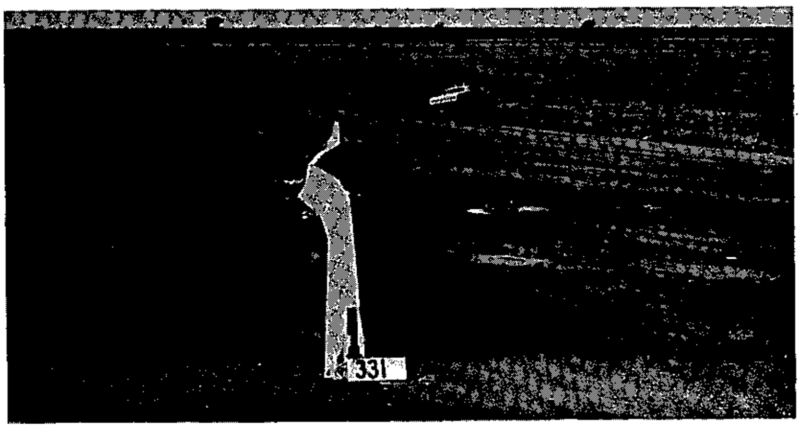


Figure 20, Post Impact Vehicle Trajectory, Test 331

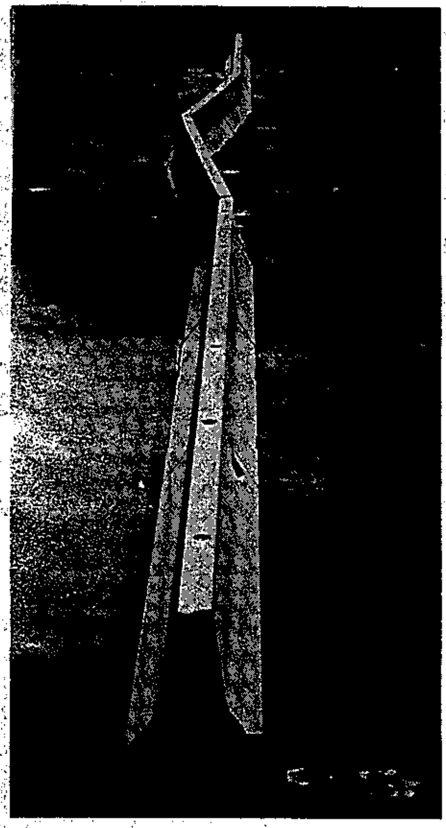


Figure 21. Post Impact Vehicle Trajectory, Test 332.

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APPENDIX

APPENDIX

Test Vehicle Equipment and Guidance System

Vehicle modifications and the guidance system used for these tests are itemized as follows:

1. The test vehicle gas tank was disconnected from the fuel supply line and drained. Shortly before the test, dry ice was placed in the tank. A one-gallon (3.79 l) safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

2. Two 12-volt wet cell automotive type storage batteries were mounted on the floor of the rear seat compartment to supply power for the remote control equipment in Test 331. The power supply was modified in Test 332 to use two 12-volt wet cell motorcycle type storage batteries which were mounted in the trunk.

3. A solenoid-valve actuated CO_2 system was connected to the brake line for remote braking. With 700 psi (4.83 MPa) in the accumulator tank, the brakes could be locked in less than 100 milliseconds after activation. Brakes were activated by remote control.

4. The ignition system was connected to the brake relay in a failsafe interlock system. When the brake system was activated, the vehicle ignition was switched off.

5. A micro switch was mounted below the front bumper and connected to the ignition system. A trip line installed near impact triggered the switch, thus opening the ignition circuit and cutting the vehicle motor prior to impact.

6. The accelerator pedal was linked to a small electric motor which, when activated, opened the throttle. The motor was activated by a manually thrown switch mounted on the top of the rear fender of the test vehicle.

7. A cable guidance system was used to direct the vehicle into the barrier. The guidance cable, anchored at each end of the vehicle path, passed through a slipbase guide bracket, Figure 1A, bolted to the spindle of the right front wheel of the vehicle. A steel angle bracket, Figure 2A, anchoring the end of the cable closest to the barrier to a concrete footing, projected high enough to knock off the guide bracket, thereby releasing the vehicle from the guidance cable prior to impact.

Figure 1A, Slipbase Guide Bracket Used for Test 331

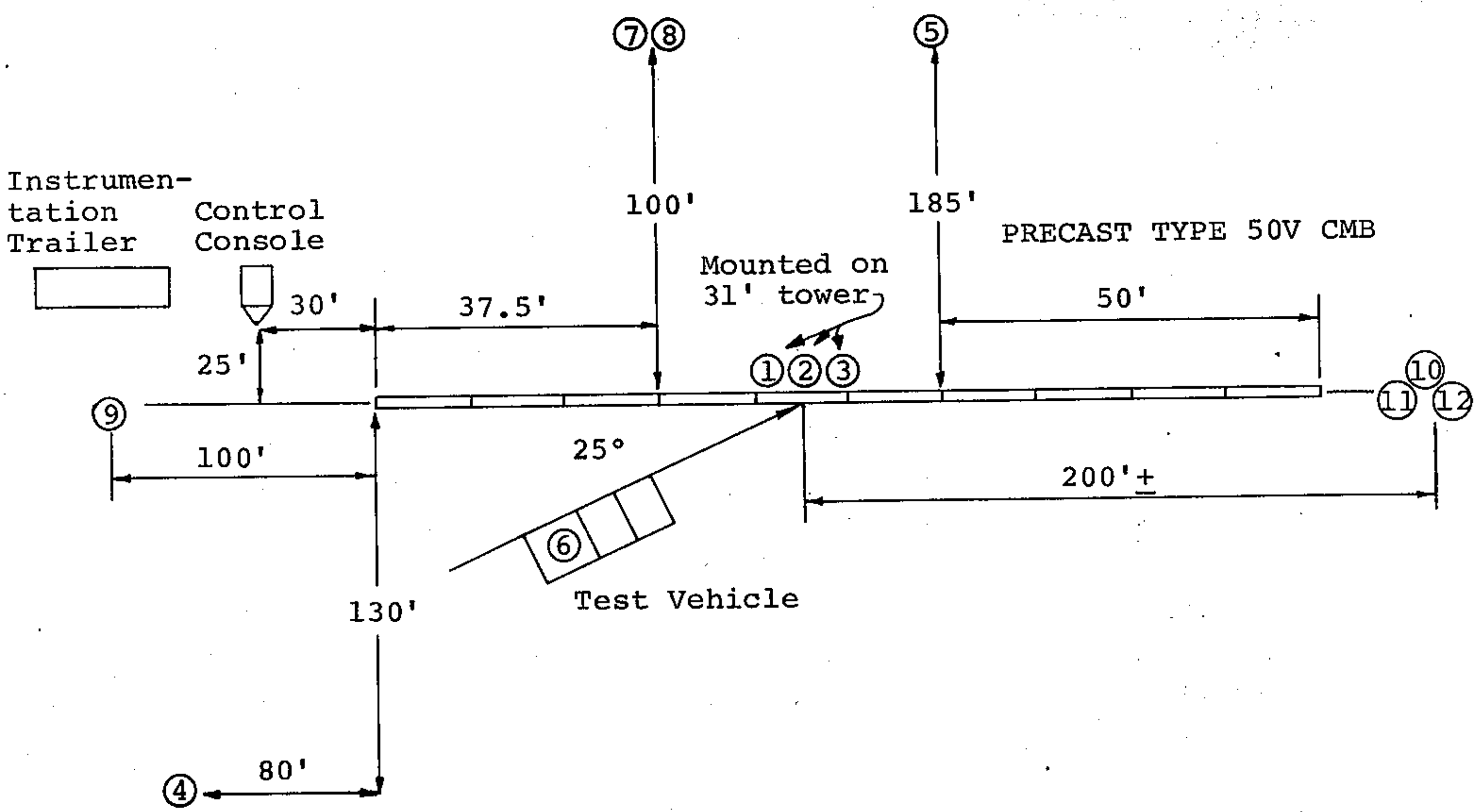
8. The remote brakes were controlled at the console trailer, Figure 3A, by using an instrumentation cable connected between

the vehicle and the electronic instrumentation trailer, and a cable from that trailer to the console trailer. Any loss of continuity in these cables caused an automatic activation of the brakes.

Figure 2A, Steel Knockoff Bracket

9. A speed control device connected between the negative side of the coil and the battery of the vehicle regulated the speed of the test vehicle based on engine revolutions per minute. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tapeswitches set a known distance apart connected to a digital timer.

Figure 3A. CAMERA LAYOUT[3]



<u>CAMERA DATA</u>[1]

①②③	Photo-Sonics Model 16mm-1B, 13mm lens, (300-350) fps[2]
④	Photo-Sonics Model 16mm-1B, 2" lens, 200 fps
⑤	Photo-Sonics Model 16mm-1B, 2" lens, (300-350) fps
⑥	Photo-Sonics Model 16mm-1B, 5.3mm lens, 200 fps; mounted inside vehicle
⑦	Redlake Locam 16mm, 12/120mm lens, 500 fps, pan
⑧	Bolex, 1" lens, 24 fps, pan
⑨	Photo-Sonics Model 16mm-1B, 4" lens, (300-350) fps
⑩	Redlake Locam 16mm, 4" lens, 500 fps
⑪	70mm Hulcher, 12" lens, 20 fps, sequence camera
⑫	35mm Hulcher, 50mm lens, 20 fps, sequence camera

1. All cameras mounted on tripods.
2. Frames per second.
3. 1 in.= 25.4mm; 1 ft.= 0.305m; 1 deg.= 0.0175 rad.

Photo-Instrumentation

Data film was obtained by using seven high speed Photo-Sonics Model 16 mm-1B cameras, 200-400 frames per second (fps) and two high speed Redlake Locam cameras, 500 fps. These cameras were located around the barriers as shown in Figure 3A, Camera Layout.

All cameras were electrically actuated from a central control console, Figure 3A.

All cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships. Additional coverage of the impacts was obtained by a 70 mm Hulcher sequence camera and a 35 mm Hulcher sequence camera (both operating at 20 frames per second). Documentary coverage of the tests consisted of normal speed movies and still photographs taken before, during, and after each impact. Data from the high speed movies was reduced on a Vanguard Motion Analyzer, Figure 4A.

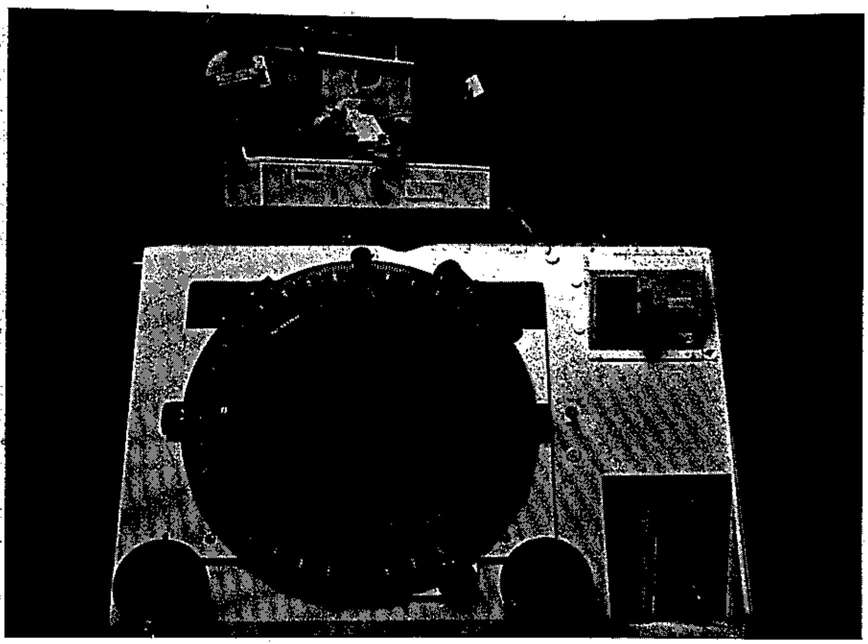


Figure 4A, Vanguard Motion Analyzer

Some procedures used to facilitate data reduction for the test are listed as follows:

1. Targets were attached to the vehicle body and to the barrier.

2. Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle/barrier contact and (b) the application of the vehicle's brakes. The impact flashbulbs have a delay of several milliseconds before lighting up.

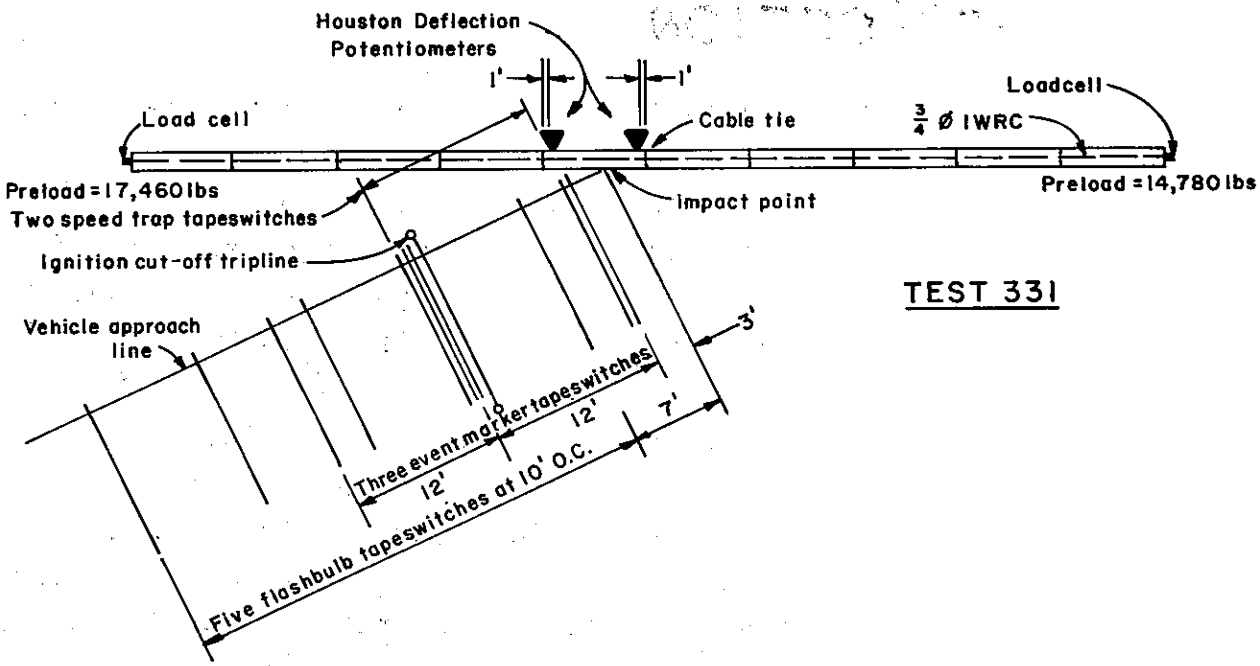
3. Five tape switches, placed at 10 foot (3.0 m) intervals, were attached to the ground perpendicular to the path of the impacting vehicle beginning about 7 feet (2.1 m) from impact, Figure 5A. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of all the data cameras and was used to correlate the cameras with the impact events.

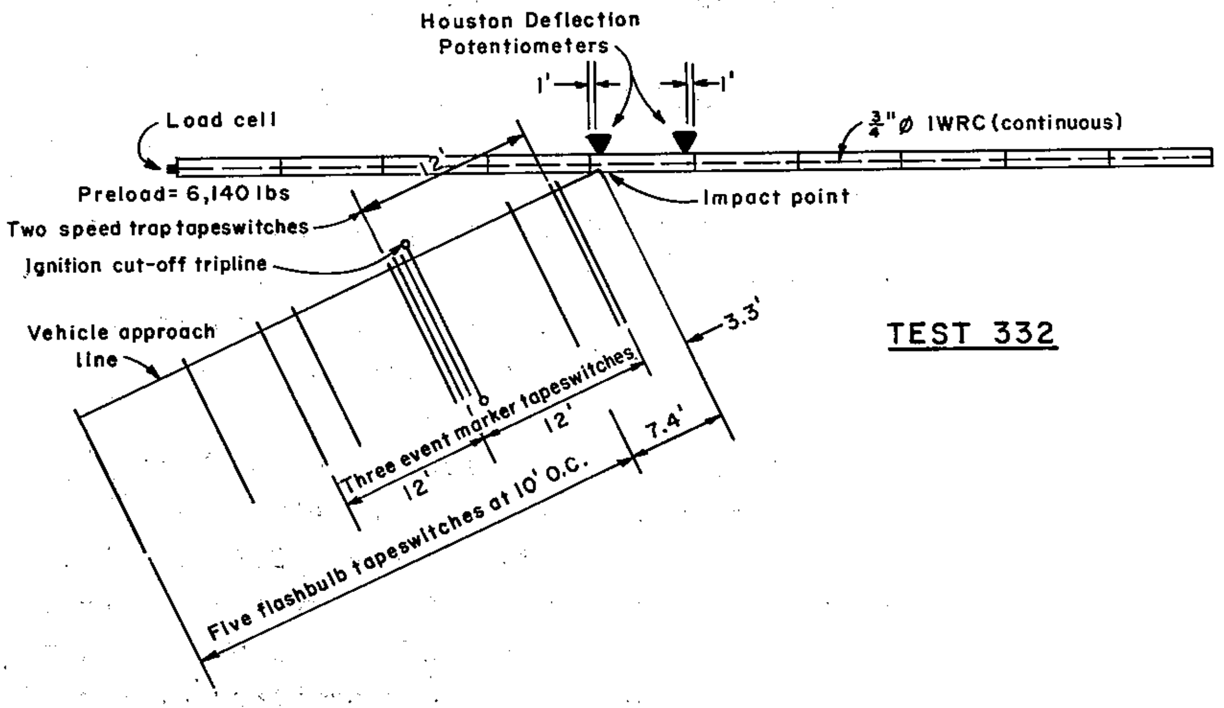
Electronic Instrumentation and Data

Data from all transducers in the test vehicle were transmitted through a 1000 foot Belden #8776 umbilical cable connecting the vehicle to a fourteen channel Hewlett Packard 3924C magnetic tape recording system. This recording system was mounted in an instrumentation trailer located in the test control area.

Figure 6A shows the locations of all transducers mounted in the test vehicles. A total of four Statham accelerometers, of the unbonded strain gage type, and three Endevco Model 2262-200 piezo-resistive accelerometers were used for deceleration measurements. Three were mounted in the head cavity of the anthropomorphic dummy. The other accelerometers were mounted on the floorboard of the test vehicle. One seat belt transducer was installed on the dummy's lap belt for each test.

Figure 5A, BARRIER INSTRUMENTATION

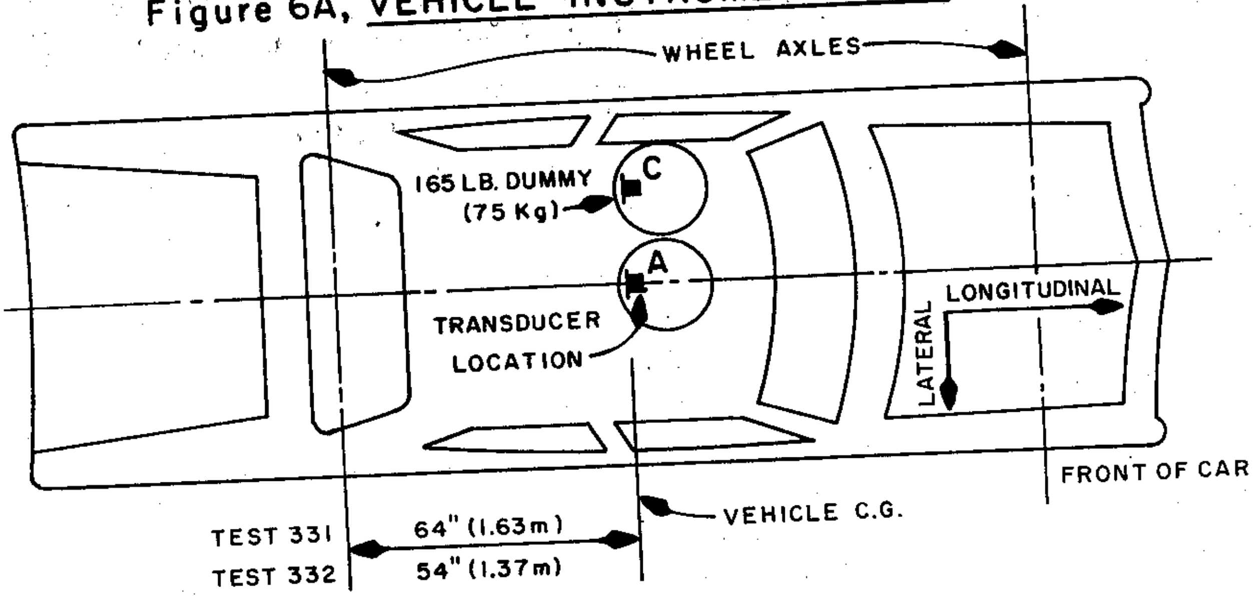




NOTES:

1. Measurements from impact point taken at base of barrier.
2. Houston Deflection Potentiometers ▼ located 6" down from top and $2\frac{1}{2}$" up from bottom of barrier at each location.
3. Load cells monitored load in cable during test.
4. Vehicle approach line was the intended path for the left wheels of the test vehicle.
5. 1 in. = 25.4 mm; 1 ft. = 0.305 m; 1 deg. = 0.0175 rad.

Figure 6A, VEHICLE INSTRUMENTATION



TEST 331 - 1973 Dodge Polara Sedan, 4680 lbs.

TEST 332 - 1970 Ford Mercury Monterey, 4600 lbs.

TESTS 331 & 332

CHANNEL NO.	TRANSDUCER TYPE	TRANSDUCER SER.NO.	LOCATION	
1	Accelerometer	590	C	Stan's Head(Dummy)Longitudinal
2	"	591	C	" " " Lateral
3		1029	C	" " " Vertical
4	"	589	A	Car Floor - Longitudinal
5	"	586	A	" " Lateral
7	"	AN92	A	" " Longitudinal
8	"	DG66	A	" " Lateral
9	Seat Belt	275	C	Across Dummy's Lap
NOTE:	Location A - is on a steel angle bracket welded to the floor at the vehicle center of gravity. Location C - is on the inside back of the head cavity of the dummy unless otherwise noted.			

Three pressure activated tape switches were attached to the ground beginning about 3 feet (0.9 m) from impact and spaced at 12 foot (3.7 m) intervals in the vehicle approach path as "event markers", Figure 5A. When activated by the test vehicle tires, these switches produced sequential impulses which were recorded with the transducer signals on the tape recorder. A time cycle was also recorded on tape concurrently with the tape switch impulses. The impact velocity of the vehicle could be determined from these tape switch impulses and timing cycles. Two additional tape switches were placed 12 feet (3.7 m) apart near the barrier specifically to determine impact speed of the vehicle on test day, Figure 5A.

Dynamic lateral deflection of the barrier was monitored during the test by four Houston deflection potentiometers placed behind the barrier segment which was impacted, Figure 5A.

Load cells were placed on the cable at each end of the test barrier for Test 331 between the end of the barrier and a steel bearing plate, Figure 5A. The cable was tightened to a load of 20,880 lbs (92.9 kN) at the upstream end and 17,950 lbs (79.9 kN) at the downstream end. These loads dropped 1700 lbs (7.6 kN) and 1100 lbs (4.9 kN) respectively by the end of the day. On test day a week later the loads had dropped to 17,460 lbs (77.7 kN) and 14,780 lbs (65.8 kN) respectively. The loads were not equal because two cables were used and connected at mid-length of the barrier. The upstream cable was tightened against a bearing plate at mid-length, and the downstream cable was not stressed as highly because the load cell was on the verge of slipping laterally out of its seating disc.

For Test 332 only one load cell was used at the downstream end because only one continuous cable was placed through the barrier. The initial load was 6140 lbs (27.3 kN). By test day two weeks later the load had slipped to 4880 lbs (21.7 kN).

After each test the tape recorder data was played back through a Visicorder which produced an oscillographic trace (line) on paper for each channel of the tape recorder. Each paper record contained a curve of data representing one transducer, signals from the three tape switches, and the time cycle markings.

Longitudinal and lateral vehicle deceleration records for each test are shown in Figures 7A and 8A. Deceleration responses of the anthropomorphic dummy and the lap belt record for each test are shown in Figures 9A through 11A.

Some of the accelerometer data records contained high frequency spikes. This data was filtered at 100 Hertz with a Krohn-Hite filter to facilitate data reduction. The smoother resultant curves give a good representation of the overall deceleration of the vehicle without significantly altering the amplitude and time values of the deceleration pulse.

Records of the Houston Deflection Potentiometers and the load cells are shown on Figures 12A through 14A.

Figure 7A . VEHICLE ACCELERATION VS TIME

LONGITUDINAL

PRECAST TYPE 50V CONCRETE MEDIAN BARRIER
WITH TENSIONED CABLE

TEST	SEGMENT/BARRIER LENGTH, FT.	ANCHORAGE	CABLE TENSION, LBS. BEFORE IMPACT
331	12.5/125	3/4" POLYSTYRENE PAD (CONTINUOUS)	16,210 (AVG.)
332	12.5/125	1" MORTAR BED	4,680

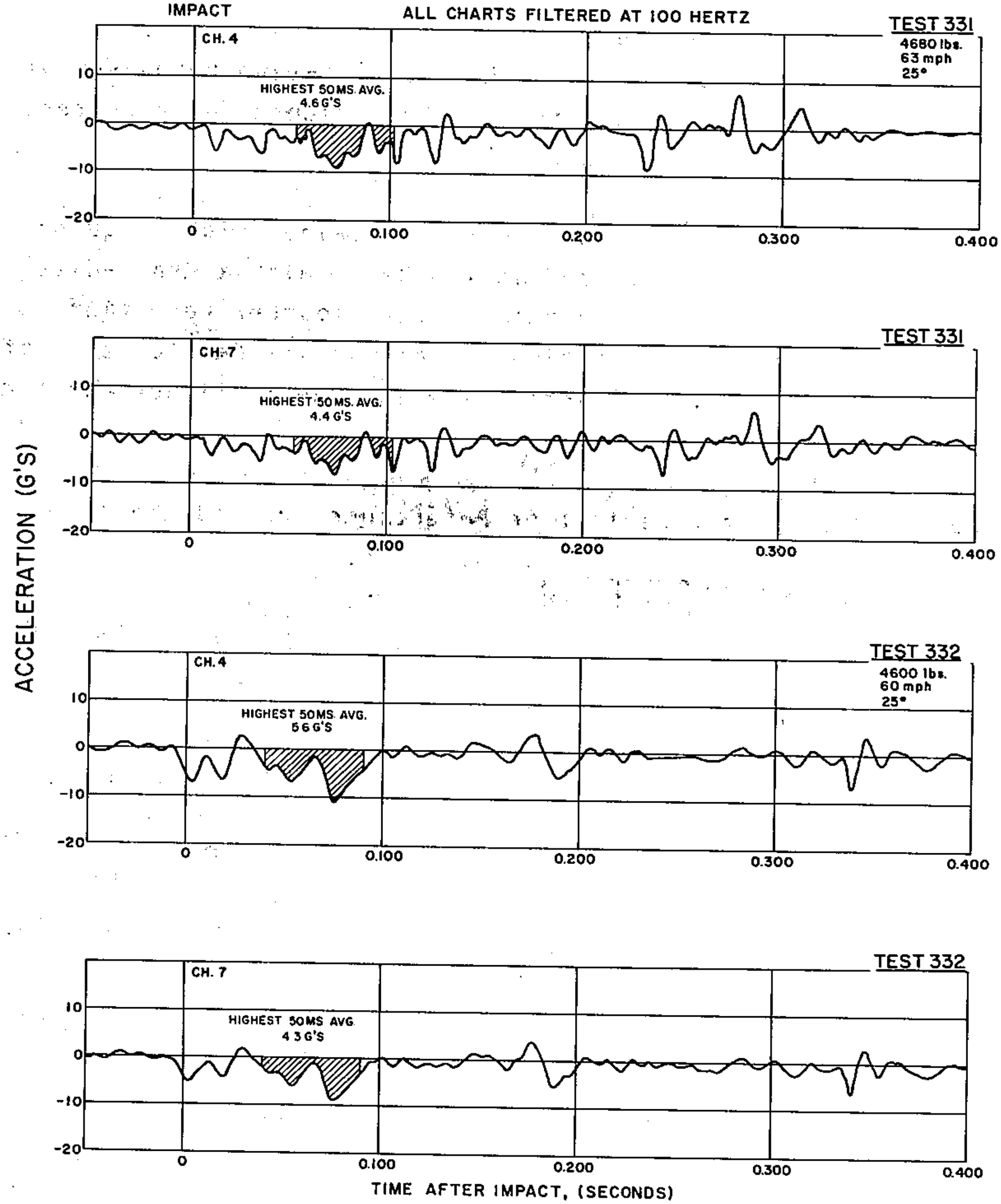


Figure 8A , VEHICLE ACCELERATION VS TIME

LATERAL

PRECAST TYPE 50V CONCRETE MEDIAN BARRIER
WITH TENSIONED CABLE

TEST	SEGMENT/BARRIER LENGTH, FT.	ANCHORAGE	CABLE TENSION, LBS. BEFORE IMPACT
331	12.5/125	3/4" POLYSTYRENE PAD (CONTINUOUS)	16,210 (AVG.)
332	12.5/125	1" MORTAR BED	4,880

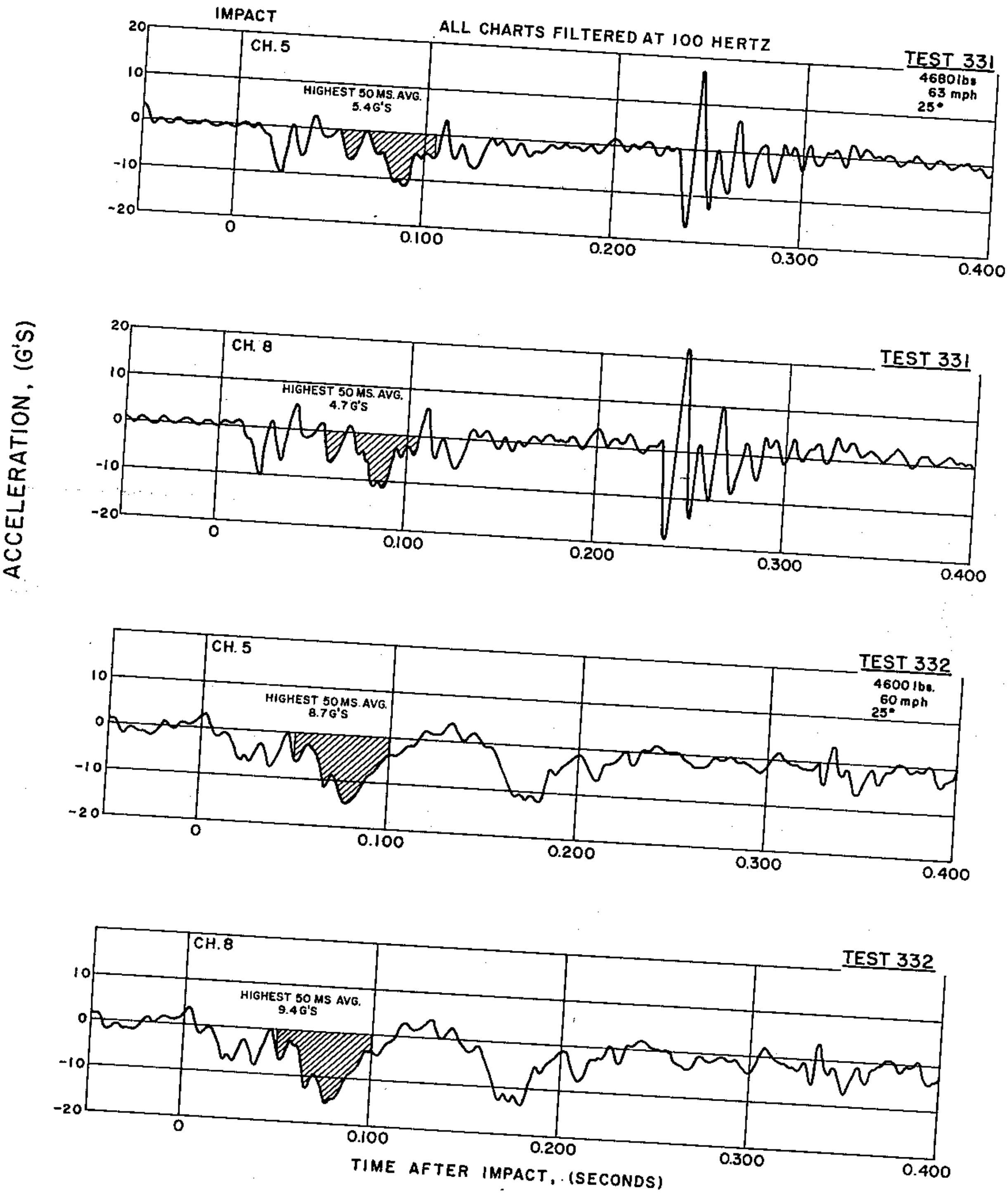


Figure 9A, DUMMY ACCELERATION VS TIME

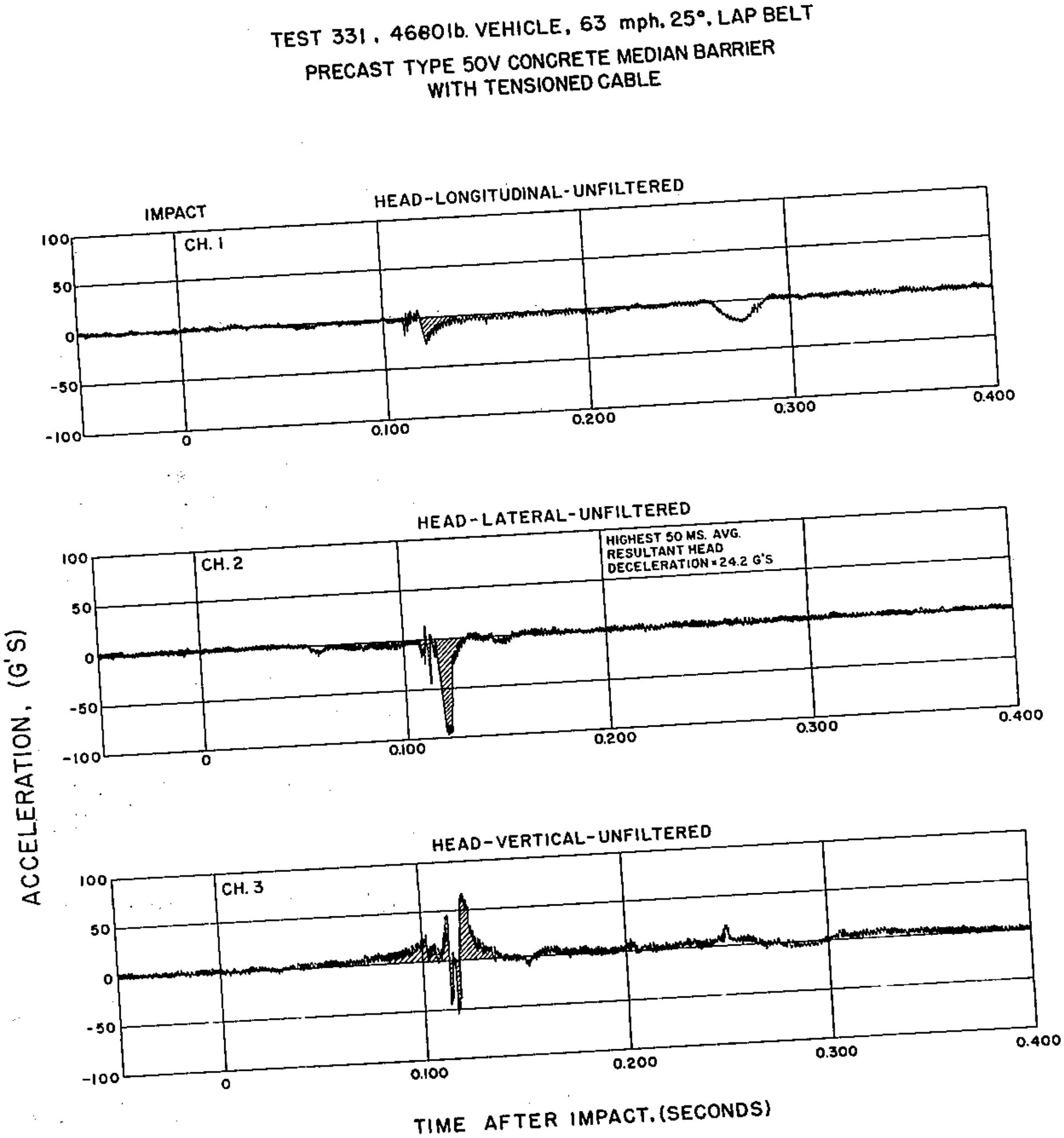


Figure 10A, DUMMY ACCELERATION VS TIME

TEST 332, 4600lb. VEHICLE, 60 mph, 25°, LAP BELT
PRECAST TYPE 50V CONCRETE MEDIAN BARRIER
WITH TENSIONED CABLE

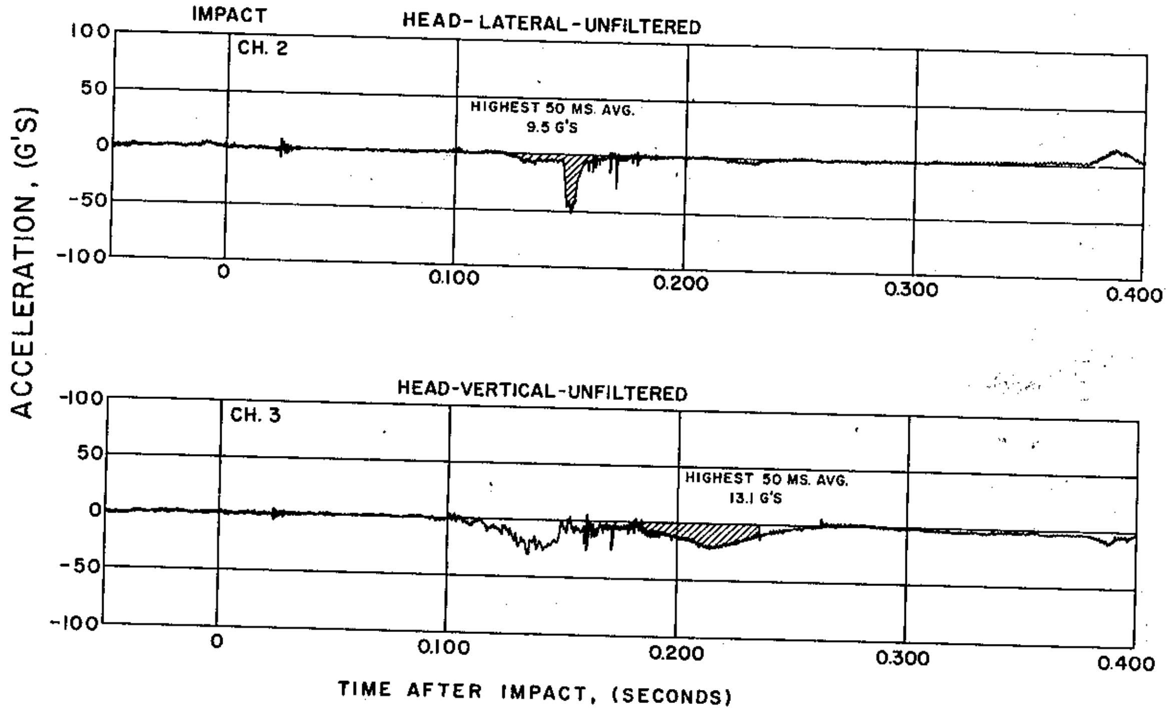


Figure 11 A, DUMMY LAP BELT LOAD VS TIME

PRECAST TYPE 50V CONCRETE MEDIAN BARRIER
WITH TENSIONED CABLE

TEST	SEGMENT/BARRIER LENGTH, FT.	ANCHORAGE	CABLE TENSION, LBS. BEFORE IMPACT
331	12.5/125	3/4" POLYSTYRENE PAD (CONTINUOUS)	16,210 (AVG.)
332	12.5/125	1" MORTAR BED	4,880

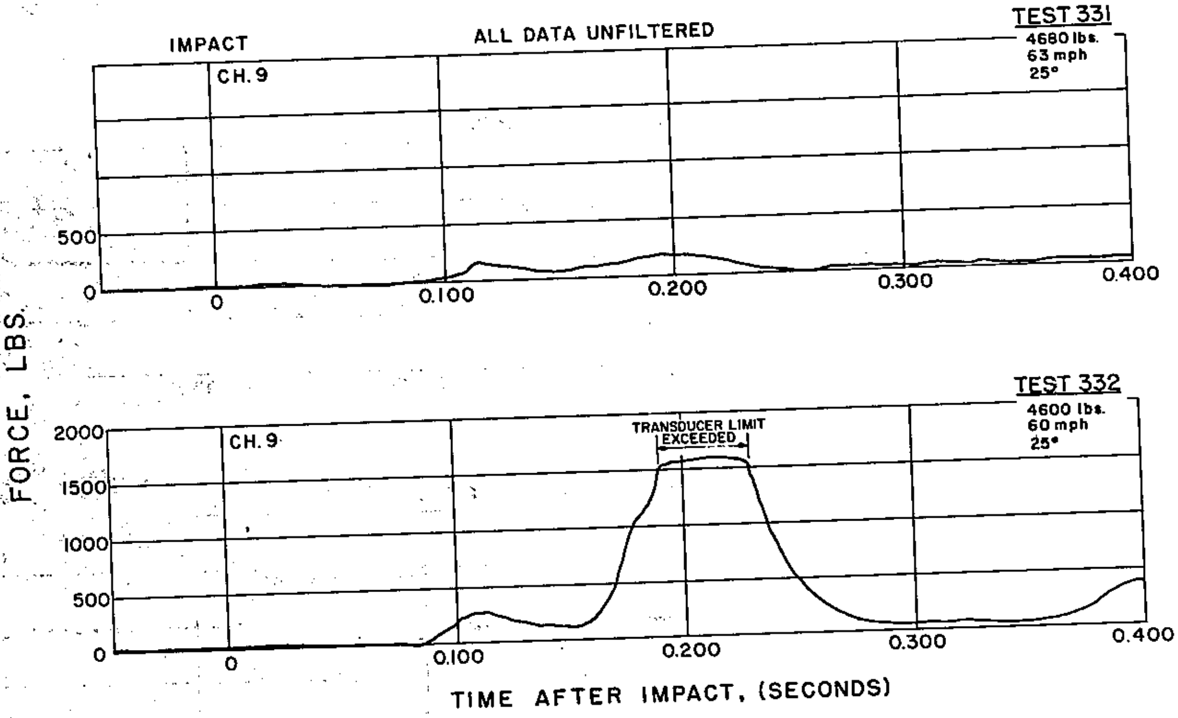
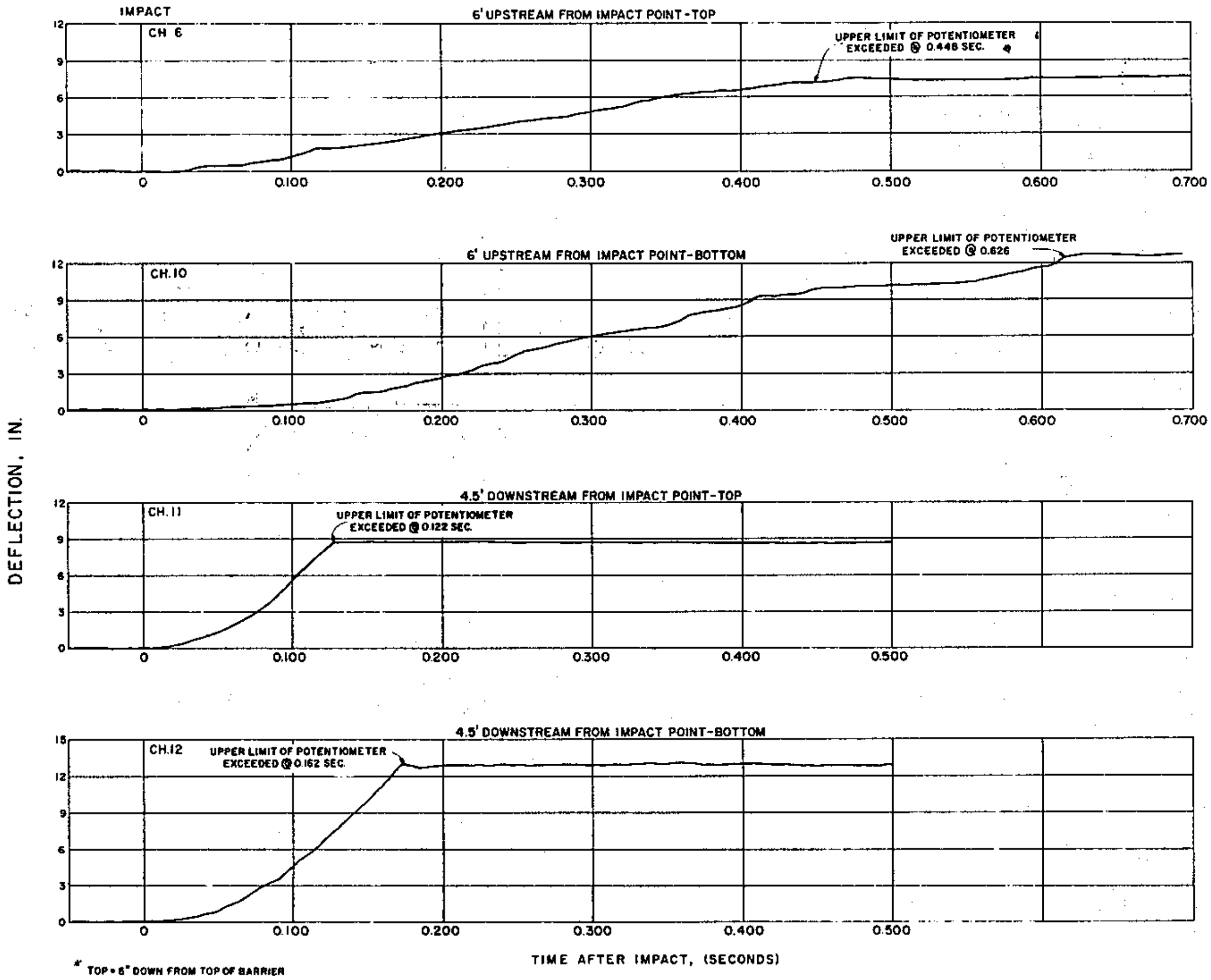


Figure 12A, BARRIER DEFLECTION VS TIME*

TEST 331, 4680 lb. VEHICLE, 63 mph., 25°
PRECAST TYPE 50V CONCRETE MEDIAN BARRIER
WITH TENSIONED CABLE

ALL DATA UNFILTERED
HOUSTON DEFLECTION POTENTIOMETERS*

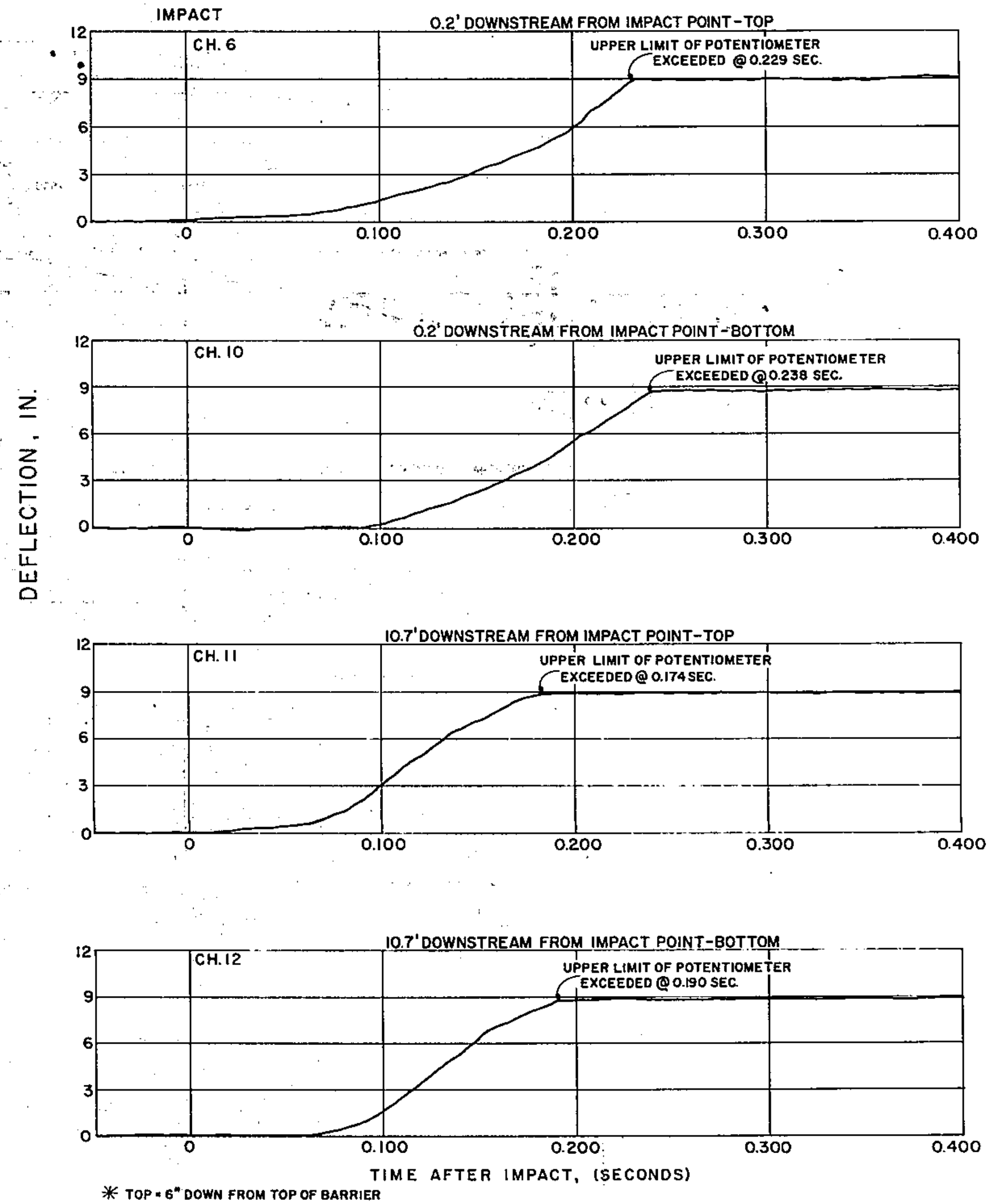


* TOP = 6" DOWN FROM TOP OF BARRIER
BOTTOM = 2-1/2" UP FROM BOTTOM OF BARRIER

Figure 13A, BARRIER DEFLECTION VS TIME

TEST 332, 4600 lb. VEHICLE, 60 mph., 25°
PRECAST TYPE 50V CONCRETE MEDIAN BARRIER
WITH TENSIONED CABLE

ALL DATA UNFILTERED
HOUSTON DEFLECTION POTENTIOMETERS*

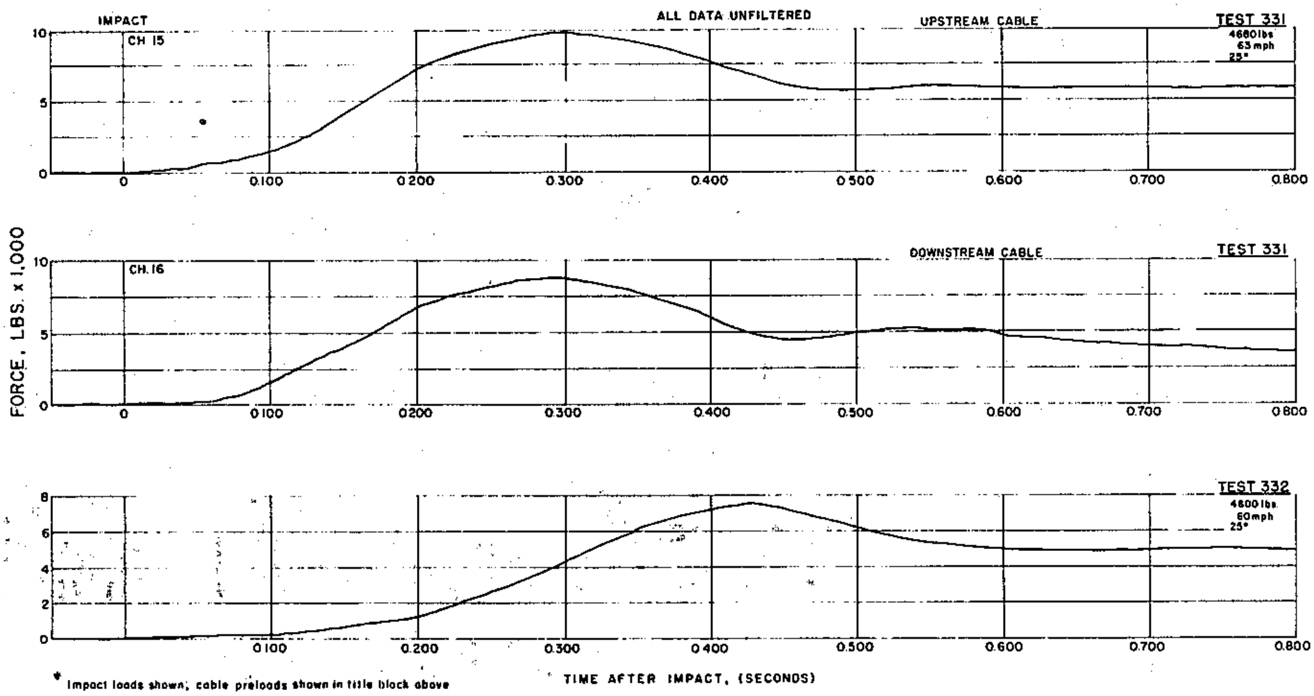


* TOP = 6" DOWN FROM TOP OF BARRIER
BOTTOM = 2-1/2" UP FROM BOTTOM OF BARRIER

Figure 14A, LOAD IN 3/4" Ø IWRC CABLE VS TIME*

PRECAST TYPE 50V CONCRETE MEDIAN BARRIER
WITH TENSIONED CABLE

TEST	SEGMENT/BARRIER LENGTH, FT.	ANCHORAGE	CABLE TENSION, LBS. BEFORE IMPACT
331	12.5/125	3/4" POLYSTYRENE PAD (CONTINUOUS)	16,210 (AVG)
332	12.5/125	1" MORTAR BED	4,980



* Impact loads shown; cable preloads shown in title block above

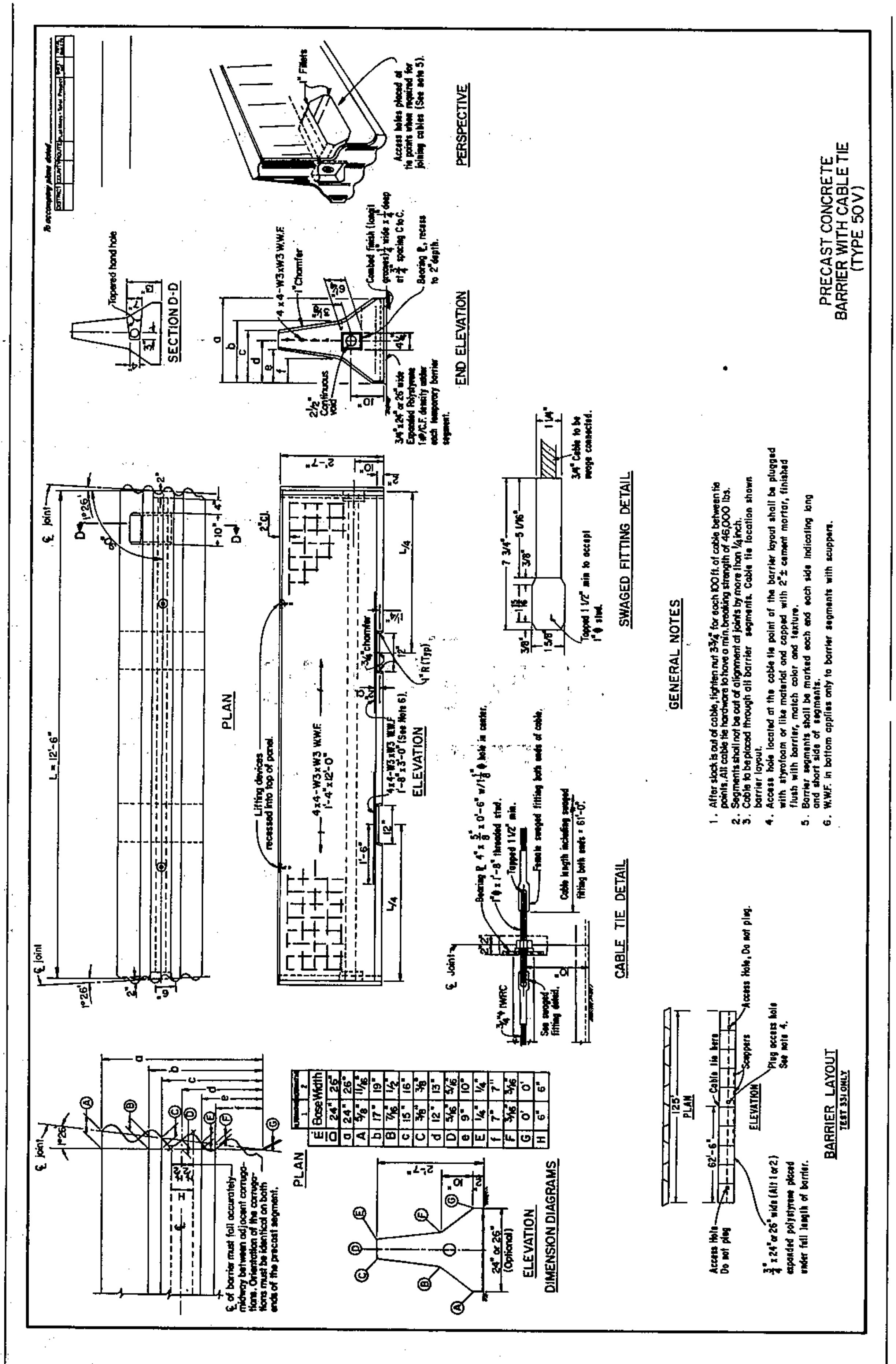


Figure 15A, BARRIER PLAN, TEST 331

Table 1A

Barrier Material Sample Tests*

Test 331

1.	Barrier Concrete 6 sacks/yd^3	Average f'_c @ 28 days = 5,780 psi (Concrete over 28 days old on test day)
2.	3/4 inch Expanded Polystyrene	Density = 1.1 lbs/ft^3 Yield Strength = 11.36 psi @ 5% compression
3.	Welded Wire Fabric 4 x 4 - W2.9 x W2.9	Complied with AASHTO M-32 and M-55
4.	3/4" Wire Rope, 6 x 19, IWRC and Swaged Fitting Assembly	Wire Rope broke at 55,000 lbs.

Test 332

1.	3/4" Wire Rope, 6 x 25, IWRC and Swaged Fitting Assembly	Ultimate Load = 60,500 lbs.
2.	Cement Mortar 4 1/2 gal H_2O/sk cement	Average f'_c @ 28 days = 6,900 psi

*1 yd^3 = 0.765 m^3 1 lb/ft^3 = 16.02 kg/m^3 1 gal = 3.79 litre
1 psi = 6.89 kPa 1 lb_f = 4.45 N

Field Installation

A permanent installation of precast CMB Type 50V 1250 feet (381 m) long was placed on Route 17 in Santa Cruz County in January, 1977. The barrier segments used were identical to those shown on the plans in Figure 15A, except that each segment had two 2 ft (0.61 m) long scuppers. The company which installed the test barrier for Test 332 was the same one that put in this field installation. Therefore, the installation procedures for both were also close to identical. Bid price on the barrier was $20.00 per lineal foot.

The maximum amount of barrier installed in one day was 600 ft (183 m). The cable was stressed in 250 ft (76.3 m) lengths. A crescent wrench was used to stress the cable "wrench tight" to a point where it became difficult to turn the wrench. It was erroneously thought at that time that the cable, having been stretched about 3 3/4 in. (95 mm) per 100 feet (30.5 m) of cable, would have a force of about 30,000 lbs (134 kN). However, the actual load was probably closer to 7200 lbs (32.0 kN), assuming the cable had not been prestretched and had an effective modulus of elasticity of 10.4 x 10^6 psi (71.7 GPa) and a metallic area of 0.222 square inches (143 mm^2).

In October, 1977 it was learned that the barrier had been hit and had moved a few inches. Several Caltrans engineers inspected the barrier and observed the following. The barrier had been soundly hit several times. Virtually all the impacts occurred in the southbound direction, and most were within a 200 ft (61 m) length of barrier. At that location there were two 12 ft (3.7 m) wide southbound lanes of asphalt concrete paving headed downhill and curving to the left on a 575 ft (175 m) radius. The median was about 6 ft (1.8 m) wide, Figure 16A.

A Caltrans computer data bank revealed the barrier had been hit six times in the southbound direction between January and September, 1977. Eight of the 12.5 ft (3.81 m) barrier segments had broken loose from their grout pads. The maximum lateral deflection at one joint was four inches (10 mm), Figure 17A. In at least one accident the vehicle straddled the top of the barrier before returning to the southbound lanes. The barrier segments were fairly tight at the joints, which may have been due in part to a tightening of the "arch" of the horizontal curve as the segments moved laterally to the east. At several of these tight joints there was some cracking and spalling of the concrete. One segment had a crack at mid-length running up the west face and part way down the east face.

Due to the high localized accident frequency, the breaking of the grout bond to the barrier segments, and the movement which had already occurred, it was decided to provide additional lateral restraint for the barrier, or replace it with a continuous cast-in-place or slipformed CMB.

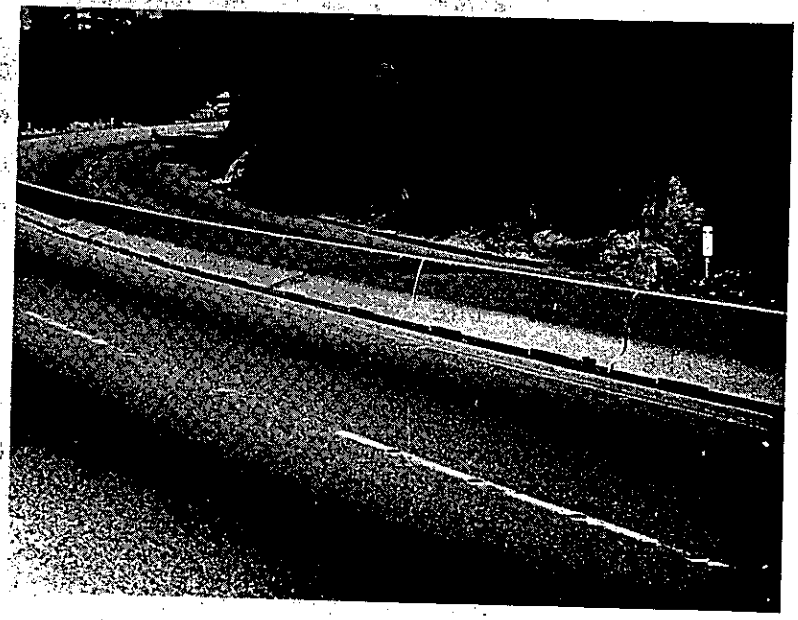


Figure 16A. Type 50V Barrier, Rte. 17, Santa Cruz County. Looking Northerly.

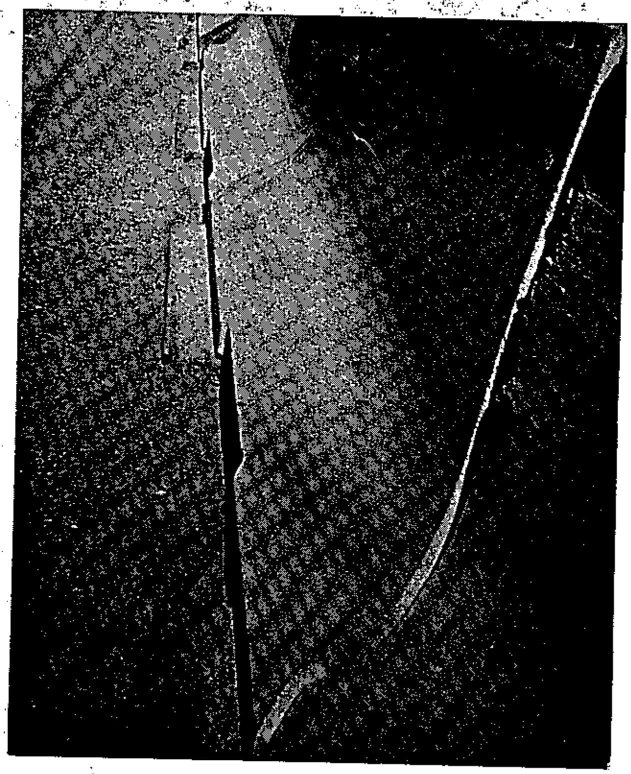


Figure 17A. Lateral Barrier Movement, Type 50V Barrier, Santa Cruz County.